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Slow Sand Filter and Package Treatment Plant Evaluation: Operating Costs and Removal of Bacteria, 'Giardia' and Trihalomethanes

Dufresne-Henry, Inc., North Springfield, VT

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SLOW SAND FILTER AND PACKAGE TREATMENT PLANT EVALUATION: OPERATING COSTS AND REMOVAL OF BACTERIA, GIARDIA AND TRIHALOMETHANES

by

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16. ABSTRACT

A two-year study was conducted on a municipally owned operating slow sand filter and a pressure diatomaceous earth (DE) filter, using the same source of supply. The systems were compared by monitoring ambient turbidity, particle count, total coliform, and standard plate count bacteria in the influent and filtered water as well as bacterial and Giardia cyst spikes.

Both methods of treatment were comparable in effectiveness for most parameters. Turbidity removal tended to be better in the slow sand filter treatment than in the DE except for the period of time following slow sand filter scraping. Particle reduction tended to be very erratic in both systems for this particular source water. Both systems removed Giardia cysts well, but effectiveness of removal by the slow sand filter tended to be affected by temperature, with better removal at warmer temperatures. At this site the slow sand filter would be the preferable method of treatment because good filtered water could be provided with a minimum of attention. Slow sand filter runs were estimated to last 100 to 200 days at a filtration rate of 0.08 m/hr (2 mgad).

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FOREWORD

The U. S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxic Substances Control Act are three of the major congressional laws that provide the framework for restoring and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This study was designed to evaluate the effectiveness of two simple filtration systems that could be used to treat high quality surface waters which might at times contain bacteria and the pathogenic cysts of Giardia lamblia. Slow sand filter and pressure diatomaceous earth filtration alternatives were compared. The results have important implications for designers and operators of small water supply systems.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

The two-year study was conducted on two simple water filtration systems applicable to treat high quality surface waters used as sources of supply for small systems. A municipally owned operating slow sand filter and a pressure diatomaceous earth (DE) filter were operated using the same source of supply. The study was designed to more fully define treatment systems which would be applicable to small supplies that may lack skilled operators and constant monitoring. The systems were compared by monitoring ambient turbidity, particle count, total coliform, and standard plate count bacteria in the influent and filtered water as well as bacterial and Giardia cyst spikes.

Both methods of treatment were comparable in effectiveness for most parameters. Turbidity removal tended to be better in the slow sand filter treatment than in the DE except for the period of time following slow sand filter scraping. Particle reduction tended to be very erratic in both systems for this particular source water. Both systems removed Giardia cysts well, but effectiveness of removal by the slow sand filter tended to be affected by temperature, with better removal at warmer temperatures. At this site the slow sand filter would be the preferable method of treatment because good filtered water could be provided with a minimum of attention. Slow sand filter runs were estimated to last 100 to 200 days at a filtration rate of 0.08 m/hr (2 mgad).

This report was submitted in fulfillment of Cooperative Agreement CR809284-01-0 with McIndoe Falls, Vermont, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period September 14, 1981, to March 15, 1985, and field work was completed as of August 1984.

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SECTION I

INTRODUCTION

Many small water systems in the United States provide potable water to a significant percentage of the national population. These systems generally serve 50-500 persons and not more than 1,000 persons.[1] Many of these water systems evolved as private or municipal systems to meet the needs of a small group of people. Such systems often exist where the raw surface and/or shallow groundwater tends to have high visual qualities and tastes acceptable to users, such as in New England, the Rocky Mountains, and the Northwest. In these areas it has been easy to provide a relatively clear and clean appearing water without treatment even though it might not always meet stringent laboratory test criteria. The psychology has frequently been that water is "free" and the clear mountain streams and springs provide safe, sanitary, and sparkling water.

In the past, many of the small systems have provided relatively safe, sanitary, and clear water; however, without adequate bacterial and chemical testing many systems have in reality been providing questionable water for the past 20-40 years and in many cases since their inception. Current information indicates that there are shortcomings in the quality of water provided by many small systems.[2] Lippy reports that there has been an increasing trend in waterborne diseases since 1951 (the trend was decreasing before that time) and this increasing trend particularly applies to small systems.[3]

The provisions of the Safe Drinking Water Act (SDWA) have placed more stringent requirements on all municipal water systems including small public supplies. The Act's requirements are based on long and well-established criteria which have generally been accepted for good, safe drinking water. However, many of the normal criteria were ignored when they only served as a guide for good quality. The smaller systems have seldom conscientiously and scientifically monitored their water to see that high water quality standards were met or that results were properly recorded.

As populations expand there is more and more land subject to intense environmental impact. This increasing impact compounds water problems and tends to increase the probability of bacterial, chemical and other water supply contamination. There are fewer and fewer water systems in mountainous or isolated country where it is possible to protect the supply from contamination.[4] Even if supplies can be protected, the pressures of land use tend to make the purchase of the necessary land extremely expensive;

thus the required protection necessary for providing water, which can be consumed directly without treatment, becomes unlikely. As man populates watersheds more completely, treatment becomes increasingly necessary.

Indigenous animals may also contribute to the contamination of water. A specific problem arising in many of the country's better water quality areas is the occurrence of *Giardia* in water supplies.[5-9] Many animals, particularly beaver and muskrats, may serve as a reservoir or carrier of this organism.[10,11] An increasing number of cases of giardiasis have been reported in the technical literature in recent years.[1,5,6,12] Outbreaks tend to occur in small water systems where water is provided to a community or to users from the "clear, pure spring or brook" treated only with chlorine, or there are times when the water supply may not have any form of treatment.

Giardia cyst chlorination requirements are more stringent than for other microorganisms. Minimal chlorination for bacterial contamination will not provide protection. Hoff[13] indicates 99% inactivation of *E. coli* with a CT (concentration multiplied by time, mg/L min) of 0.04, poliovirus 1 with a CT of 1.7, *E. histolytica* cysts with a CT of 90, and *G. lamblia* cysts with a CT of 50-250 at a pH of 6.0, with a temperature of 5°C and free chlorine concentration ranges between 0.1 and 8 mg/L. The same reference shows that free chlorine is more effective than chloramines, and that low temperatures require much higher CT values. Also, Hoff[13] indicates that low pH is more effective than high pH and for 99% inactivation the CT is also a function of free chlorine residual. Waters at 1°C and at a pH of 7.8 require a CT of about 500 at a free chlorine residual of 2 mg/L and a CT of 300 at 5 mg/L. These data would indicate (by extrapolation) that at 0°C (several months of the year at McIndoe Falls) the CT value should be about 500 for a free chlorine residual of 0.5 mg/L and a pH of about 6.8. Also, unlike bacterial exposure, ingestion of a very few *Giardia* cysts will usually produce the parasitic disease even though only a few cysts have been ingested. The probability of small-water-system users becoming exposed to this organism is increasing.

Dependence on chlorination to protect water users from *Giardia*, bacteria, or other disease-producing organisms generates many concerns. Trihalomethane concentrations tend to be more severe with heavy doses of chlorine so that such treatment of a water supply is not entirely satisfactory. Additional treatment, even for very small systems, is necessary.

The small water systems in rural areas have great operational difficulties in meeting any or all of these natural and imposed problems.[14] Therefore, it may be difficult for these systems to comply with the SDWA requirements. These small water systems can be compared to the systems and needs of developing countries throughout the world. Small systems need treatment which is simple and reliable because the responsible local organizations do not have the funds required to provide elaborate water systems,[4] and the amount of technical and professional input is usually limited.

If water systems using surface water supplies, are to meet the SDWA and provide a safe and palatable water to their users, some form of treatment beyond disinfection generally will be required. According to current criteria, many consumers are presently receiving poor quality drinking water. Such poor delivered water may exist in some large water systems in large communities, but small systems have major delivered water quality deficiencies because of a lack of adequate treatment.

The deficient conditions have shown themselves in many states. For example, a report on Vermont indicates that at least 45% of the Vermont population has been drinking water that is known to be below minimum health standards.[2]

Presently there are many methods of treating water to remove bacteria, turbidity, color, and other contaminating materials.[15-18] Many of these techniques are extremely effective and almost any quality of raw water can be converted into safe, clear drinking water. Cost and technical know-how are the limiting factors which are generally scarce in small water systems in the United States as well as in developing countries. The types of installations needed for these locations are simple, inexpensive, fail-safe systems which will meet health and technical criteria for a satisfactory drinking water.

Simpler systems from the past need to be looked at in light of new criteria and compared with more sophisticated and more automated systems referred to as "package plants." From past practice it has been shown that the slow sand filter is one of the simplest and most promising systems. A renewed interest has developed in slow sand filters,[19,20] particularly in Europe and in developing countries.[21]

At the present time we do not know how well the simpler systems will remove bacteria, turbidity, and _Giardia_ cysts, particularly under heavy loading conditions.[15] Current data are needed to guide consulting engineers and reviewing authorities toward the best combination of treatment which will meet the needs of the small water facilities. This information will be helpful in the United States as well as developing countries.

The DE pressure filtration system was selected as the "package plant" comparison. Such a system is also relatively simple, low initial cost, is compact, and readily available. Such filtration systems could provide a quick response to small system treatment needs.

The objectives of this study were developed to address the concerns of the small water system, with particular emphasis on _Giardia_ cysts and trihalomethanes. The principal objectives addressed by this study were:

1. To determine the effectiveness and efficiency of slow sand filtration and package diatomaceous earth (DE) on removal of bacteria, turbidity, and _Giardia_ under various loading conditions.

2. To spike bacteria and Giardia cysts into the raw water under varying loading conditions to determine when the loadings might produce a break-through in the systems and contribute bacteria and Giardia to the effluent.

3. Observe, record, and evaluate the level of technical expertise required to operate the systems; observations to be based primarily on ambient operating conditions.

4. Obtain operation data in terms of hours and costs associated with operating and maintaining the system; costs related to chemical additions, cleaning, restoring the systems to operation, and similar well-defined operational requirements.

5. To evaluate the potential for, and formation of, trihalomethanes (THM) in the untreated water and compare the results with values from the effluent from the slow sand filter and a diatomaceous (DE) package treatment plant, treating the same source of supply.

SECTION II

CONCLUSIONS

A. Slow Sand Filtration

1. Provided dependable water treatment with a minimum of attention but at high capital cost.

2. Removed turbidity to less than 1 NTU 99.19% of the time (after the first 100 days of operation the effluent values were below 1 NTU 99.68% of the time) and 72% of the time the values were 0.2 NTU or less (raw water 1.45 NTU or less 72% of the time).

3. Reduced total coliform to 10/100 mL or less 86% of the time (raw water 1300/100mL or less 86% of the time and standard plate count to 10/1 mL or less 94% of the time (raw water 500/1 mL or less 94% of the time) under ambient load conditions.

4. The average bacterial content in the effluent under ambient conditions was 4/100 mL (raw water 440/100 mL) for total coliform and 15/mL (raw water 520/mL) for standard plate count.

5. Removed massive spikes of total coliform and standard plate count bacteria from raw water at temperature conditions above the range of 5-10°C.

6. Did not remove bacteria as efficiently at temperatures below 5°C and particularly around 0-1°C. Spiking studies demonstrated the temperature effect with removal of total coliform deteriorating from 98% to 43% and standard plate count from 98% to 80% in 9 days at 1°C. At 6 to 11°C removal remained at an average of 99% for total coliform and 97% for standard plate count during a 15-day spike.

7. Removed *Giardia* cysts very dependably, 99.98% or better, under warm temperature conditions.

8. Did not remove *Giardia* cysts as completely at low temperatures, under 7°C, 99.36 - 99.91% removal.

9. Heavy bacterial and *Giardia* cyst applications to the filter at the same time under cold conditions appeared to show signs of competing for the biologic treatment capability. *Giardia* cyst removal was reduced to 93.7% and total coliform and standard plate count dropped to 43% and 79-82% reduction respectively.

10. Did not show any significant effect in the reduction of trihalomethane precursors.

11. Erratic particle reduction in the 7-12 µm range did not compare with the *Giardia* cyst removal results.

12. Particle reduction did not provide a dependable method of predicting *Giardia* cyst removal in this full-scale operating filter experiment and with this particular water.

13. The mature filter recovered from cleaning within two weeks to provide dependable bacteria and turbidity removal. Limited data showed that at times under warm weather conditions the effluent water contained satisfactory bacteria and turbidity concentrations sooner than in two weeks.

14. Required a minimum of 1.5 hr of operation per day to properly run the system and meet monitoring requirements.

B. Pressure Diatomaceous Earth Filtration

1. Removed *Giardia* cysts dependably using Celite 503®* with 99.97% reduction.

2. Bacterial removal for total coliform showed reductions of 86% or better for 70% of the samples and for standard plate count 80% reduction or better for 70% of the samples.

3. Eighty-six percent of the average run values for total coliform showed 8/100 mL or less (96/100 mL in raw water) and 82% of the average run values for standard plate count showed concentrations of 12/mL or less (127/mL in raw water).

4. The average bacterial content in the effluent under ambient conditions was 38/100 mL for total coliform (690/100 mL in raw water) and 6/mL for standard plate count (60/mL in raw water).

5. Under spiking conditions the average percent reduction for total coliform was 97.6% and for standard plate count 92.7% reduction. Eighty percent of the average run values showed reductions of 95.8% or better for total coliform and 87.5% or better for standard plate count.

6. Under spiking conditions the effluent contained an average of 122/100 mL of total coliform (10,860/100 mL in raw water) or 107/100 mL or less for 77% of the run averages (2400/100 mL in raw water) and for standard plate count the average was 47/mL (1300/mL in raw water) and 7/mL or less for 77% of the run averages (2800/mL in raw water).

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

7. Provided rapid cycle time and flexible filter water production capability.
8. Required more operator time and attention when running than the slow sand filter.
9. More mechanically skilled operator needed than required for the slow sand filter.
10. The process is labor, energy, and materials intensive in comparison with the slow sand filter. DE filtration requires daily attention when running, more electricity when pumping to terminal head loss, and daily quantities of DE to run the filter.
11. Particle reductions in 7-12 µm range were erratic for this water. Slime organisms may have contributed to the erratic results.

SECTION III

FURTHER RESEARCH

A. Slow Sand Filtration

1. Study the effects of temperature on bacterial removal to more completely define the critical temperature range where removal and percent reduction shows a marked change.

2. Study high bacterial and organic loadings at high temperatures to determine when high removal expectancy may be detrimentally affected by anaerobic conditions in the filter. Low temperatures should also be involved to determine at what temperatures the impact would be minimal.

3. Study the effect of temperature on Giardia cyst removal to more completely define the transition temperature range which appears to be around 5 to 7°C and below which cyst removal tends to be less complete.

4. Study the effect of high bacterial loads on the removal of Giardia cysts as they compete for the biologic treatment capability, under various temperature conditions and particularly under cold temperature conditions.

5. Compare fluorescent treated cyst removal with viable cyst removal under the same spiking conditions at low (0-1°C), medium (5-7°C), and high (20°C) temperatures.

6. Investigate the fate of tagged and viable cysts in the filter under cold and warm temperature conditions.

7. Define cyst removal by studying the penetration of cysts into the filter for cold to warm temperature ranges.

B. DE Filtration

1. Study the removal of Giardia cysts at various filtration rates at water temperatures of 0-1°C. Cold weather (-13°C, 25 mph wind) housing was not available for extended cold weather operation.

2. Other research is not suggested as it would appear that most of the questions arising from this research would be water specific related and only applicable to the particular water.

C. General

1. Study the effects of prechlorination or chloramine treatment on both slow sand filtration and DE filtration at low, medium, and high temperature ranges. This might have some advantages insofar as treatment is concerned, but would be contributing to complication of the need for simple, foolproof or failsafe systems for small water supply situations.

SECTION IV

FACILITIES, EQUIPMENT AND OPERATION

GENERAL

McIndoe Falls is a small community in the town of Barnet, Vermont. This community is located along the Connecticut River on the eastern side of the state about 50 mi south of the Canadian border and 13 mi south of St. Johnsbury, Vermont. The community is an unincorporated village of about 180 people with a post office address. The incorporated operating organization for municipal activities of the water system is Fire District #3. This body was developed and organized in order to own, manage, and operate the water system as a municipal facility.

Originally the residents of McIndoe Falls obtained their water from individual or community springs. There were about 18 springs providing the water to the residents of the community. Highway construction of I-91 (circa 1974) passed between the spring water supplies and the settlement. In order to replace the spring sources of water, the Vermont Highway Department decided to construct a municipal water facility rather place 18 or more water lines under the interstate highway. As a result the Highway Department contracted for the design of a slow sand filter treatment system. The new system consisted of a surface source, slow sand filter treatment, disinfection, and a distribution system to serve about 170 people.

Uncertainties developed concerning the adequacy of the replacement supply and treatment and thus a system modification was necessary. McIndoe Falls decided to augment the surface supply with groundwater. As a result of discussions, the Highway Department installed three wells to augment the existing source of water. As a result of these actions, the total capacity of the slow sand filter was not needed. It was therefore possible to do field research on one of the two slow sand filters in the treatment plant. By conducting the research on one filter the other filter could be maintained in a standby condition with the community obtaining a majority of its water from the well source.

WATER SOURCE

The surface water source for the McIndoe Falls treatment facility consisted of two impoundments, having about 50 acres of wetlands plus about 10 acres of open water. The open water pond is known as Coburn Pond. The drainage basin is about 1.5 mi^2. The source of most of the water is from springs rather than from direct runoff. Since the area is primarily a wetland, the water depth is minimal with a maximum depth of around 15 ft, but much of the water is in the order of 2 to 8 in. The bottom tends to be silty with standing and emerging vegetation. There are several beaver dams and lodges throughout the impoundment. The gravel road going through the area forms part of the dam at the lower impoundment and another road provides a divider between the lower and upper impoundment and also a road passes through the upper end of the upper impoundment.

The drainage basin is primarily forested with only a minimal amount of open land used for grazing animals or raising hay. No more than 5 houses are located in the drainage basin, all reportedly using septic tanks, and tile field disposal systems and are located a minimum of 500 ft from the impoundment, with one exception - a house across the road from the water plant and on the downstream side of the impoundment dam and culvert.

The physical characteristics of the impoundment are different from the usual raw water source. Usually the desired source is a reservoir or stream with minimal vegetation, sediment, and organic material. The raw water quality, however, was found to be satisfactory for treatment. The raw water was tested over a period of time before the plant was built and the results are summarized in Table 1.

PERSONNEL

The McIndoe Falls water system is managed by the Prudential Committee of Fire District #3. This Committee consisted of Robert Sager, Wallace Thrall, and Russell E. Pearl, Chairman. The treasurer was Louis Thomas, Jr. The Fire District has operated and maintained the system by retaining a part-time operator. The operator during the project was Dale Dunbar, who was responsible for the operation of the municipal system including the wells, the physical facilities of the treatment plant, and the distribution system.

During the study, Mr. Dunbar assisted with the research work by collecting samples, taking readings, reporting temperatures, turbidity, chlorine concentrations, and in general assisting with the data collection activities of the research. His participation was particularly important during weekends and holiday periods when regular personnel scheduling would have been difficult.

SLOW SAND FILTER

Description

The McIndoe Falls slow sand filter treatment system consists of a stream intake from the impoundment stream, control manhole, two slow sand filters, two reservoir-chlorine contact tanks, two hypochlorinators, head-loss gauges, and manual valves for flow control. Figures 1 and 2 are schematic representions of the plant arrangement.

TABLE 1. PREDESIGN RAW WATER QUALITY [22]

Characteristic	Number of Samples	Average	Minimum	Maximum
pH	9	7.6	6.9	8.5
Turbidity (NTU)	9	2.1	0.4	4.6
Color (CU)	9	24	0	50
Odor (T.O.N.)	4	0	0	0
Alkalinity*	9	69	40	122
Hardness*	9	63	32	94
Iron**	9	0.55	0.02	1.5
Manganese	9	0.03	0	0.04
Copper	3	0.17	0.1	0.2
ABS/LAS	8	0	0	0
Chloride	9	2.2	1.0	4.3
Nitrate-N	9	0.14	0	0.3
Nitrite-N	9	0.002	0	0.01
Ammonia-N	9	0.10	0.03	0.37
Arsenic	2	0.005	0	0.01
Barium	3	0	0	0
Cadmium	4	0	0	0
T. Chromium	4	0	0	0
Lead	4	0	0	0
Mercury	3	0.0011	0	0.0017
Silver	4	0	0	0
Zinc	4	0.15	0	0.30
Fluoride	8	0.039	0	0.10
Sodium**	5	136	122	155
Sediment	5	Some visual evidence in all samples		

*Values for alkalinity and hardness expressed as mg/L of $CaCo_3$
**Iron to sodium, expressed as mg/L

The plant intake consists of two 25-ft lengths of 4-in. PVC pipe, 3 ft on centers. This pipe is laid in the bottom of the stream in a 12-in. layer of 1½-2-in. marble chips, bed size 6 ft by 40 ft. This intake filter serves as a prefilter and at the same time provides some help toward controlling pH and iron. The stream flows over the intake and the amount not used continues on as part of the impoundment overflow. The original design did not provide flashboards to maintain water depth at the intake filter.

The control manhole is provided with inlet and outlet pipes and valving to shut off water from the intake filter and drain the bottom of the manhole. There is also an overflow bypass and a plant intake pipe in the manhole. The inlet line from the prefilter is 4-in. PVC, the overflow is 8-in. AC, the overflow bypass is 10-in. AC, and the filter inlet line is 4-in. cast-iron.

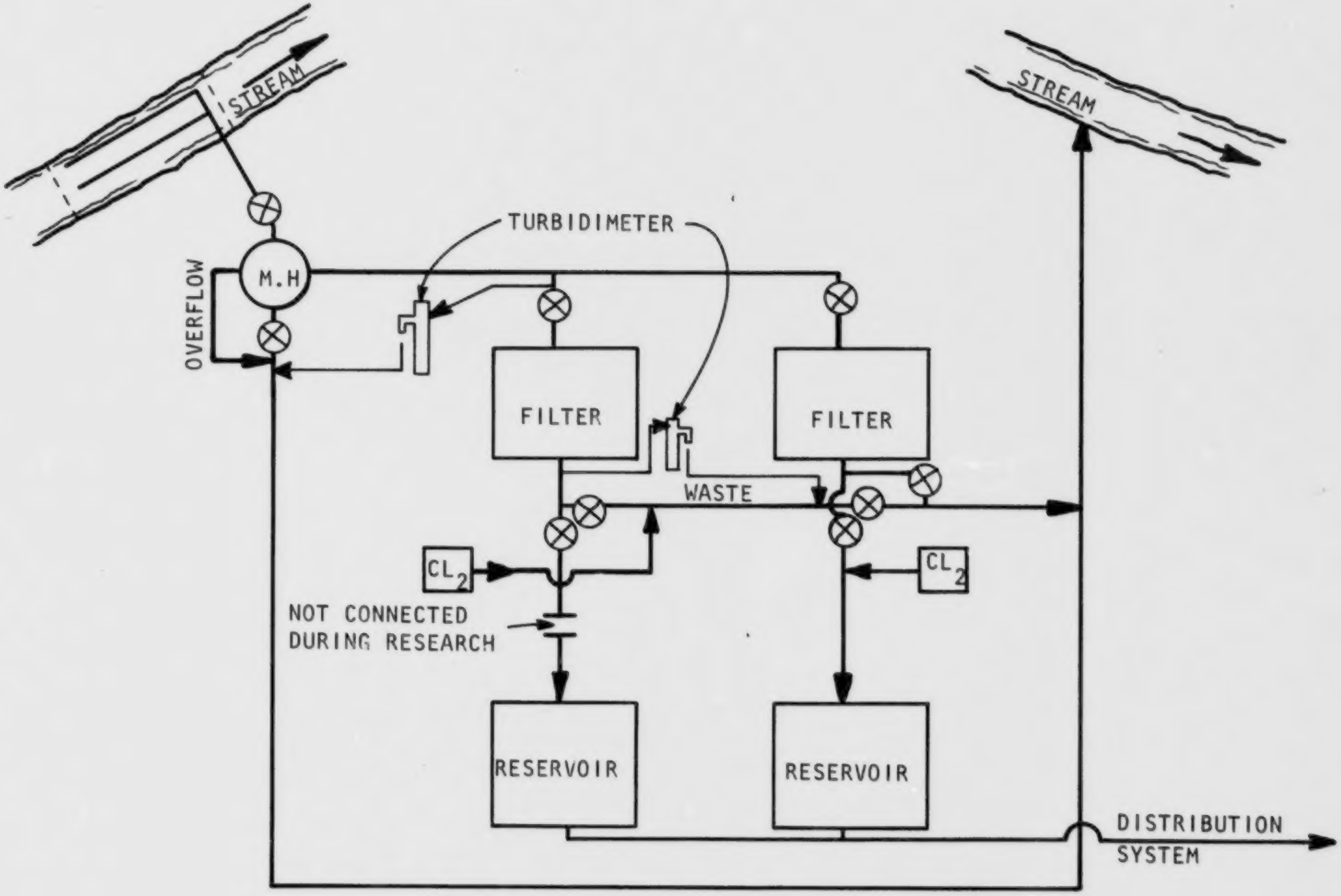

STREAM
STREAM
TURBIDIMETER
M.H
OVERFLOW
FILTER
FILTER
WASTE
CL_2
CL_2
NOT CONNECTED
DURING RESEARCH
RESERVOIR
RESERVOIR
DISTRIBUTION
SYSTEM

Fig. 1. Schematic Flow Diagram of Slow Sand Filter as Used for Research

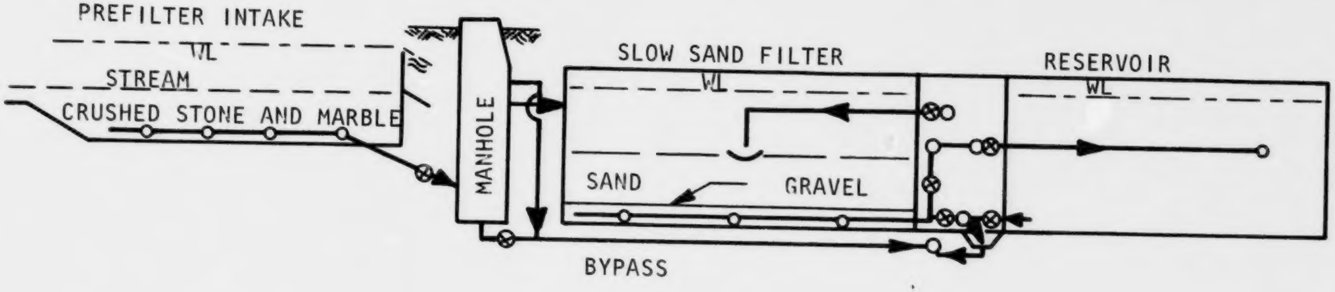

PREFILTER INTAKE
WL
STREAM
CRUSHED STONE AND MARBLE
MANHOLE
SLOW SAND FILTER
WL
SAND
GRAVEL
BYPASS
RESERVOIR
WL

Fig. 2. Schematic Cross Section of Slow Sand Filter Treatment System

The two covered slow sand filters are 20 x 20 ft each with concrete floor, walls, and roof. The filters were constructed with 42 in. of graded sand and 15 in. of graded gravel. The inlet to the filters is 4-in. cast-iron discharging at the center of each filter. There are 4 x 6-ft access hatches in one corner of each filter. The water depth over the sand is 4.7 ft and the clearance from the sand to the concrete cover is 5.3 ft. The 4-in. perforated PVC underdrains in the 15 in. of graded gravel are connected to galvanized pipe discharging to the reservoirs.

The two chlorinators feed hypochlorite solution to the effluent from the slow sand filters and discharge to the reservoirs. The hypochlorinators are Chem Tech International. They discharge into the two 20 x 20-ft covered reservoirs which have a combined capacity of 54,000 gal This provides five days of storage and contact time at current use (2.5 days at design capacity) with one filter operating.

Modifications

For the purpose of conducting research, the slow sand filter system was modified (Fig. 1) in order to provide better operation and to ensure that there would not be any cross connection to the standby filter or the potable water supply.

Operational difficulties at the filter intake had been encountered during previous winter test operation activities. Anchor ice had tended to form on the bottom of the streambed sealing the filter intake and preventing water from entering the treatment plant. Flashboards were installed to a depth of 18 in. at the headwall immediately downstream from the intake. These boards ensured that a layer of ice would form over the intake structure and thus anchor ice would not form. This was a successful modification in that at no time during three winters of operation was there any problem with ice formation and thus no reduced flow to the slow sand filters.

Another major modification was to separate the two filters. The inlet pipe to the second slow sand filter, which served as a standby filter, was physically disconnected by removing the flange connection and capping the end of the pipe so that all the flow went into the first sand filter, the one to be used for the research studies. This ensured that there would be no cross connection between filters.

The effluent line from the research sand filter was physically disconnected from the reservoir connection and discharge pipe. The only way the effluent could leave the research filter was through the waste pipe. This line was modified so that the filtration rate could be controlled and measured. This was accomplished by installing a 2-in. PVC pipe from the waste line valve to the bypass sump in the floor of the piping chamber. This 2-in. pipe was raised 1-1/2 ft at the end in order to provide positive head at the underdrains under extreme head loss conditions.

The head loss gauges were modified by installing new plastic gauges on the influent and effluent pipes to ensure that no cross connection would occur with the existing filter or the reservoir. A meter stick was installed along with the plastic tubing so that head measurements could be read to the nearest half centimeter.

The hypochlorinators were repaired and placed back in operation but the discharge was modified so that chlorine would be applied to the effluent water going to waste. This approach was selected because the water being used by the community was not being chlorinated. The only source of water being used was from wells; their alternate water supply and the well water did not need chlorination. Chlorine residuals were read by sampling the effluent discharging from the effluent waste pipe. This did not provide contact time but the approach did provide data for chlorination operation.

Sand Characteristics

The original sand installed in the filter at the time of construction was utilized for this research. The sand had been selected from sources in New England. The sand is hard, clean, and of a light brown coloration. The sand was selected to meet the design specifications of a uniformity coefficient (uc) of not greater than 2.5 and an effective size (es) of 0.25-0.35 mm.

Before and during construction the sand was sampled several times to establish the size characteristics. The range of values for the filter sand as installed and used for this research is shown in Table 2. At the end of the research samples were taken from the filter at two different locations and two different depths at each location. The results of these sieve analyses are also summarized in Table 2.

These results indicate that the sand is fairly coarse with a rather large uniformity coefficient.

TABLE 2. FILTER SAND - CONSTRUCTION ANALYSES

Size/Uniformity	Average	Maximum	Minimum	Number of Samples
Construction Analyses				
Effective Size (mm)	0.33	0.34	0.30	7
Uniformity Coefficient	2.74	3.00	2.57	7
Post Research Sample Analyses				
Effective Size (mm)	0.33	0.34	0.33	4
Uniformity Coefficient	2.81	2.94	2.71	4

These results show that there is good agreement between the construction reports and the post research sampling although the design specification of a uc of 2.5 was not met. The average of all results is an es of 0.33 mm and a uc of 2.76 for the sand filter used in the study.

SLOW SAND FILTER OPERATION

The slow sand filter was operated at a filtration rate of 0.08 m/hr throughout the study. Originally it had been planned to study several rates, but it was found that summer flows of the source water could be so low that it would be difficult to operate at higher rates. By concentrating on the lower rate, which is applicable to the smaller type systems, a more thorough evaluation could be provided. Also this approach helped conserve the Giardia cysts available by not spreading the number of cysts over several loading situations and thus possibly reducing the concentration of cysts available for each spike.

At the 0.08 m/hr rate the filter operated with about 4.5 ft of water over the surface of the sand. The flow rate was manually controlled and adjusted by timed-weighed and volume flow measurements. Time checks of flow rate were made about once every two weeks or when flow discrepancies were suspected. Weighed flow checks were made about one time every month to ensure that flow was maintained at the prescribed rate.

Head loss was recorded regularly depending on the rate at which the head loss developed. Values were obtained every month and more frequently when there appeared to be more rapid head loss changes developing. Filter runs were generally from 6 to 12 mo. The shorter runs were frequently the result of arbitrary cleaning for additional cleaning and recovery studies rather than the result of a need to clean the filter because of head loss.

Cleaning

Filter cleaning was accomplished by drawing the water down below the sand surface after shutting off the inflow. This required shutting down the filter about 12 hr before the filter was to be cleaned. The cleaning process consisted of using flat shovels to scrape off between 0.75 and 1.5 in. of sand from the surface of the filter. The sand had to be physically transported by hand in the filter space, thrown by shovel out of the filter through the hatchway doors and placed on the surrounding land. The time and level of effort involved in cleaning the filter was recorded as a part of the study data. The low head room inside the filter (about 5 ft) made standing erect in the filter impossible. This made cleaning more laborious and contributed to longer cleaning time than would be expected at a slow sand filter with adequate headroom.

After being cleaned, the filter was placed back in operation by slowly filling it with water until the full elevation of 4.5 ft was obtained. Refilling required about 24 hours. After the filter was full, the effluent line was adjusted to the desired flow rate by weight-time measurements. Head readings were observed at the time of start-up.

Recovery

Recovery studies were conducted after the filter was cleaned. These studies involved collecting daily bacterial samples of influent and effluent for three weeks after cleaning. Four recovery studies were conducted, two studies using the natural raw water, and two by spiking with sewage to determine the recovery effect under heavy bacterial load conditions.

Chlorination

The two chlorinators at the water plant were rehabilitated and one placed in operation in order to evaluate chlorination requirements. The point of application of the chlorine was the waste pipe coming from the filter underdrain because the contact facilities normally built into the plant were the clear wells and these could not be used for the research study. However, normal hypochlorinator operation was instituted so that the same hypochlorite dilution requirements and activities would be involved as would be practiced if the chlorine were being applied to the reservoirs as originally designed. Toward the end of the study some actual chlorine application situations were reported because the other filter was placed in operation to provide water for the municipality. Chlorine solution was made up about every three days during the chlorination operation studies and residuals were measured and recorded every day with an appropriate chlorine comparator.

DIATOMACEOUS EARTH PACKAGE FILTER

Description

Two pressure filters were utilized at McIndoe Falls to study comparative removal by DE. The first experiments conducted using DE were performed on a rented unit having cloth septums and a filtering area of 0.74 m^2 (8.0 ft^2). The system consisted of a pressure filter tank with influent and effluent connections, pressure gauge, and air bleed-off valve. The influent line contained a water meter, rotameter, and connections for body feed and bacterial spiking. Slurry tanks with mixers and precoat and body feed pumps were used to feed the DE during operation.

The rest of the DE experimental work was performed on a unit loaned from EPA. This was a pressure unit with stainless steel septums having a filter area of 0.93 m^2 (10 ft^2). The system consisted of a pressure filter tank with influent and effluent connections, pressure gauge, air bleed-off, body and precoat slurry tanks with mixers, precoat pumps, body feed pumps, water meter on the influent line, and rotameter flow control on the effluent line.

Raw water for the DE filters was obtained from the raw water pump installed over the inlet manhole. The pump was a 3/4 HP, 110 V., 7.5 A., 7 to 21 gpm jet pump which could operate at up to 60 psi.

Installation

The installation for the two pressure filters was very similar in each case. Figure 3 is a schematic diagram of the pressure filter installation, showing the EPA filter. The raw water pump was located over the plant control manhole. The water from the manhole was the same as the water going to the slow sand filter and had been subjected to the prefilter action in the stream intake. A 1.25-in. PVC pipe was connected from the pump to the pressure filter's enclosure. One-in. rubber pressure hose was used to connect the water meter and all facilities. At the raw water pump a valve bypass was provided to regulate flow rates. The raw water was pumped to the inlet of the rented pressure filter through a water meter and a rotameter and through only the water meter for the EPA filter. The raw water inlet line was provided with body feed and spiking connections. The precoat slurry tank was installed with a mixer, treated water inlet hose, and feed pumps to provide recirculated precoat at two times the normal filtration rate. The body feed slurry tank was provided with treated makeup water with a stirrer and a positive displacement slurry pump. Valves were installed in the piping to direct the inflow, body feed, recirculation, and effluent in order to manage the operation during a complete cycle of a filter run.

At the time of installation all septums were checked and cleaned and no leaks were detected. The second pressure filter did have some problems with the fitting between the septum holder and the effluent header. These connections were sealed using the existing O-rings and a silicone sealant to ensure a tight fit between the two parts.

DE Characteristics

One grade of DE was primarily used in the filtration studies; a finer grade was used for leak checking and detection. The DE grade used for most of the studies was Celite 503®, and the fine grade for leak detection was Filter Cel®. Two pressure runs were also conducted using Celite 512®. Only one grade was used to make the evaluation and comparison studies under varying operating rates, turbidity conditions, and sewage and *Giardia* spiking. Most of the available *Giardia* cysts were to be used on the slow sand filter. By using one grade of DE, a minimal amount of spiking on the DE filter would be required. The particle size of the DE grades are shown in Table 3.

TABLE 3. PARTICLE SIZE (µm) OF DIATOMACEOUS EARTH[23]

DE Type	Median	Minimum	Maximum
Celite 503®	23	3.5	98% finer than 125 µm
Celite 512®	15	1.5	98% finer than 90 µm
Filter Cel®	7.5	0.5	99% finer than 60 µm

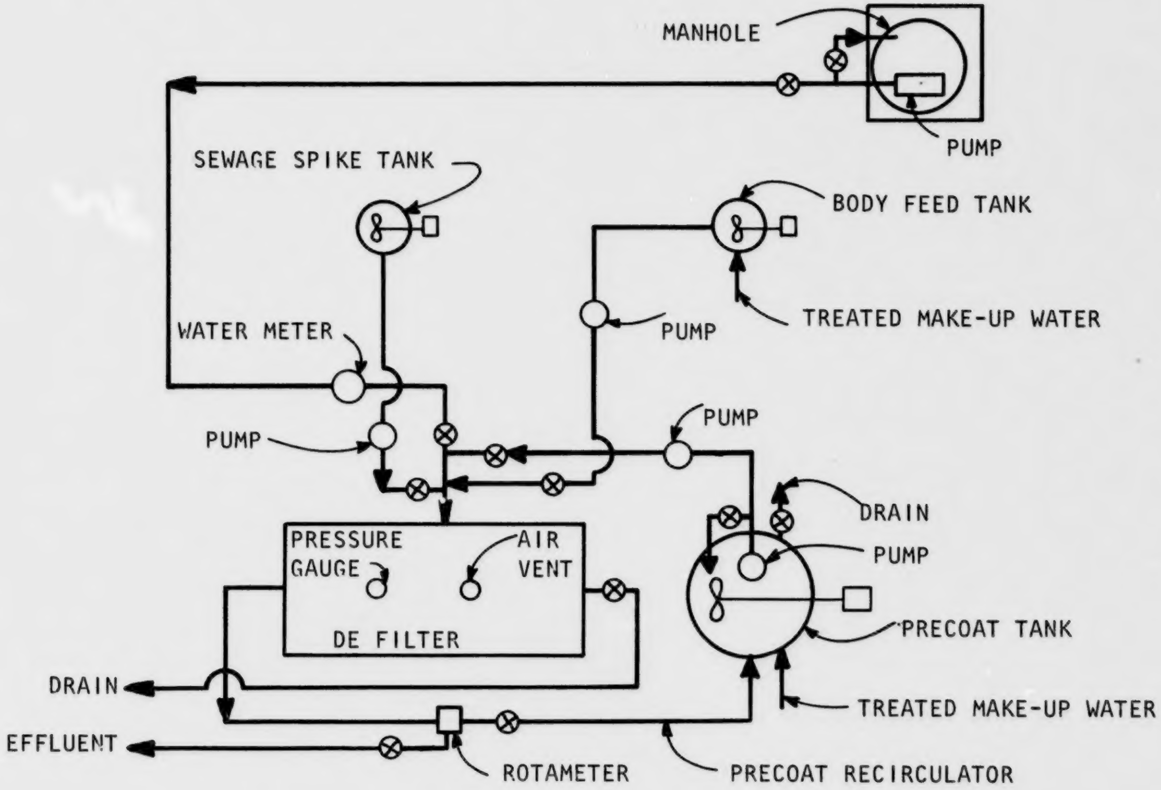

MANHOLE
PUMP
SEWAGE SPIKE TANK
BODY FEED TANK
TREATED MAKE-UP WATER
WATER METER
PUMP
PUMP
PUMP
DRAIN
PUMP
PRESSURE GAUGE
AIR VENT
DE FILTER
PRECOAT TANK
TREATED MAKE-UP WATER
DRAIN
EFFLUENT
ROTAMETER
PRECOAT RECIRCULATOR

Fig. 3. Schematic Flow Diagram of DE Treatment System

DE Filter Operation

The pressure filters were placed in operation after cleaning by checking the septums, closing and bolting the filter and the cover, and adjusting all valves for the precoat operation. The air vent was left open to permit air bleeding during the filling of the pressure tank with treated water and the first application of precoat, until all air had been exhausted from the system. The raw water pump was started and the estimated amount needed to provide full raw water flow conditions was temporarily bypassed. The filter tank influent valve was maintained in the closed position until the filtration run was started.

The precoat slurry was prepared by filling the slurry tank with treated water, (at the same time filling the pressure filter) agitated with a slurry stirrer, and DE added to give 0.2 lb per 1 ft^2 of filter septum surface (1.6 lb for the 8 ft^2 (0.74 m^2) filter and 2.0 lb for the 10 ft^2 (0.93 m^2) filter). This mixture was allowed to mix thoroughly. The precoat inlet filter valve and effluent recirculation valve on the pressure filter were opened and the precoat slurry pump started. The air vent was left open during filter filling and until all air had been evacuated and was then closed during precoat and filtration. The precoat feed was circulated until the tank contents turned clear. A cup (approximately 60 g) of Filter Cel® was added to the clear precoat feed water and circulated until the water was again clear, indicating that there were no leaks in the system.

The filtration run was started by slowly and simultaneously opening the raw water feed and closing the precoat feed line. This was done simultaneously in order to prevent bumping of the cake on the septum. The precoat slurry pump was shut off and the effluent to the body feed tank closed and the filter effluent valve opened to discharge. The raw water feed was adjusted to the desired filtration rate. Initial pressure readings and influent and effluent turbidity and bacteria samples were collected. Readings and sampling were performed about four times during each run, approximately every 1/2 to 1 hr. Runs were not generally carried to terminal head loss, but were usually terminated at about 15 to 20 lb of pressure depending on the length of time to reach that pressure. However, for some situations when pressure tended to build up rapidly the run was conducted for a minimum of 2 hr or until maximum pressure was reached. The air vent was checked from time to time to purge any air which might have gained access to the filter.

The runs were terminated at 15 to 20 lb because above that point the pressure affected the raw water flow rate, particularly at high filtration rates. Except for very short run times, sufficient data could be obtained which could be used to extrapolate performance to terminal pressures. Also, more experimental runs could be conducted each day.

The shut-down procedure involved stopping the body feed and raw water pump. The drain and air vent were opened and all the water was drained from the filter by gravity. After the water had drained from the filter, the pressure vessel was opened and the cake removed from the septums by water spray. The filter was flushed out, free of DE or any other debris.

BACTERIA AND GIARDIA SPIKING

For special study situations bacteria and also *Giardia* cysts were spiked to the slow sand filters and the DE filters. The bacteria spiking was performed to increase the loading conditions in order to evaluate removal and other effects on the filters when subjected to high bacterial concentrations. *Giardia* spiking had to be performed since there was no indication that *Giardia* cysts were naturally present in the raw water.

Continuous feed of *Giardia* cysts to the slow sand filter raw water could not be accomplished at the filtration rate of 0.08 m/hr (13.5 gpm) because of the number of cysts required. Preliminary tests indicated that it would be desirable to have about 2000 cysts in a sample to provide good recovery in the laboratory analysis work. This would mean feeding a minimum of 2×10^6 cysts/day during any *Giardia* cyst removal study. Sufficient quantities of *Giardia* cysts were not available to use continuous spiking. High concentration, instantaneous spiking provided the best use of the *Giardia* cysts.

A positive displacement bellows pump (with variable speed control to regulate volume fed per unit of time) was used for bacterial spiking. By adjusting the spiking pump, it was possible to accurately control the quantity of spiking fluid fed during the time spiking was in progress.

The source of bacteria was primary effluent from the St. Johnsbury, Vermont sewage treatment plant. Primary effluent was selected in order to have a minimum of solids content and also to ensure that there was no chlorine residual present in the water. The effluent was used for spiking purposes, either full strength or diluted, depending on particular runs, and the desired bacterial concentration. Samples of the sewage were collected each time a new or fresh batch of sewage was used. The determination of total coliform and standard plate count bacteria provided concentration information whereby the amount of bacteria applied could be calculated and compared with the effluent samples. Fresh sewage was obtained daily for all runs and stored in a cool place to ensure that anaerobic conditions would not develop during the studies.

An evaluation was made to relate bacterial concentrations obtained by grab samples of the spiking sewage and the average concentration of bacteria over the 24-hr spiking time. Total coliform and standard plate count tests were performed on the samples in the laboratory at 10°C and 20°C with time. Average count ratios were obtained as shown in Table 4.

TABLE 4. RATIO OF AVERAGE GRAB SAMPLE BACTERIAL CONCENTRATION TO 24-HOUR AVERAGE CONCENTRATION

Temperature, °C	Standard Plate Count	Total Coliform
10	0.82	0.92
15	0.97	1.10
20	1.12	1.30

These ratio values were used in adjusting the calculated bacterial spike concentrations.

Giardia spiking also used the positive displacement bellows pump which was set at 600 mL/min in order to provide thorough flushing action and to prevent settling of cysts. A known number of cysts (between 2 x 10^6 to 22 x 10^6) in a 4 mL aliquot was placed in the intake funnel to the spiking pump. As the spike of Giardia suspension was pumped into the inlet or raw water line, either to the slow sand filter or the DE filter, a minimum of 6 separate flushes of water (10-20 mL each) was placed in the spiking pump funnel. These spiking flushes ensured that all of the Giardia would be flushed through the system and pumped into the raw water.

SECTION V

EXPERIMENTAL PROCEDURES AND METHODS OF ANALYSIS

GIARDIA

Sources

The G. lamblia cysts for this project were obtained from human stool samples through the cooperation of the Vermont Health Department, and the Mary Hitchcock Hospital in Hanover, New Hampshire. The Health Department samples were all previously treated with 5% formalin solution as they were patient samples which had been requested by examining doctors. The Hanover samples were obtained from the hospital laboratory as untreated viable cyst-containing stool samples, mostly obtained from patients in the hospital.

Cyst Concentration

The Giardia cysts for spiking purposes were separated from fecal samples and concentrated to develop known quantities of cysts in the spiking sample tubes. The concentrate was produced from the fecal samples obtained from the Vermont Health Department and the Mary Hitchcock Hospital.

Separation was accomplished by mixing 1 part fecal material with 3 parts of 5% formalin. This suspension was well mixed and then poured through a layer of wet gauze placed in a funnel to provide an initial crude separation. Filtrate was collected in 15 mL conical centrifuge tubes. The strained volume placed in each tube was about 1 mL. (At times 50 mL conical centrifuge tubes were used and 3 mL of the strained mixture was collected in each tube.) Distilled water was added to the centrifuge tubes to make the suspension volume up to 10.0 mL (30.0 mL). The suspension in the tubes was thoroughly mixed and then centrifuged in a swinging bucket centrifuge (500 to 650 g) for 2 min. After centrifugation the supernatant in the tube was decanted. The remaining sediment normally had a volume of around 0.5 to 0.75 mL (1.5 to 2.25 mL), if not, the volume was adjusted to this range. The sediment in the centrifuge tubes was then diluted with 9 mL (27 mL) of 5% buffered formalin and thoroughly mixed. To this mixture was added 3 mL (9 mL) of ethylene acetate, the tubes were stoppered, and shaken vigorously in an inverted position for at least 30 seconds. After shaking the stopper was removed and the tubes centrifuged at 450 to 500 g for 1 to 2 min. The plug of debris was removed from the sides of the tube by scraping around the sides with an applicator stick. The top three layers in the centrifuge tubes were decanted and a cotton swab was used to remove debris adhering to the glass. The pellet in the bottom of the tubes was retained as this contained the cysts. The pellets from all the centrifuge tubes for any run were combined and suspended in 5% formalin solution to produce cyst concentrations of about 5.3×10^5/mL to 6.4×10^6/mL. The cysts were then stored for labeling.

Preservation

Cysts in this research were preserved by both refrigeration and formalin treatment. All cyst suspensions were stored in refrigerators (0° to 4° C) at all times whether treated with formalin or not. All cysts and samples were transported in coolers with ice or cold packs. All cysts and filter effluent samples were treated with 5% formalin except for a few special filter effluent sample situations. In a few cases the effluent samples were stored in distilled water because the background material would be reduced but not the formalin treated cysts. The formalin treatment helped ensure that cysts would not be destroyed readily and also it eliminated the health hazard to laboratory personnel.

Counting

Cyst enumeration procedures were performed under the direction of Dr. Robert Sjogren at the University of Vermont. Polycarbonate membrane filters were transported on ice from the field in 1-qt wide mouth glass jars or 240-mL, plastic, sample cups. Jars or cups containing the folded membrane filters in distilled water or 5% buffered formaldehyde were stored at 0° to 4°C at the University of Vermont.

Filters were processed by cutting them into 5-cm pieces and placing the pieces in a 40-oz glass Waring® blender cup. Any excess fluid in the sample jar was poured into the blender cup, and the jar was washed twice with about 20 mL of distilled water. This was added to the blender cup, and the volume of fluid for blending was made up to 200 mL. A few drops of liquid dishwashing detergent (Ivory®) previously diluted to 1:100 were added. The cut membrane was blended for 30 seconds at 20,000 rpm using a single speed blender base.

The contents of the blender were strained through two thin layers of cheese cloth held in a large glass funnel supported by a 1 L glass beaker. The blender cup was washed two or three times with about 30 mL of distilled water from a spray bottle. The cut pieces of membrane were stirred briefly with a wooden applicator stick during this process. The cheese cloth was then carefully squeezed to remove excess water. All fluid was collected in the 1 L beaker.

After the filtrate was collected, it was distributed among several 50-mL, glass, conical centrifuge tubes which were spun at 450 g for 15 min using a swinging bucket rotor centrifuge. The supernatant was then carefully aspirated from each tube, leaving the undisturbed pellet in the bottom along with about 1 mL of liquid. The pellets were again suspended and the contents of the 50-mL tubes were combined in a 15-mL conical glass centrifuge tube. All of the 50-mL tubes were rinsed in serial fashion three times with distilled water that was also added to the 15-mL tube. The Pasteur pipette used to transfer material was also rinsed and that liquid was added to the 15-mL tube. The 15-mL tube was then centrifuged in a clinical table top swinging bucket centrifuge for 15 min at 450 g.

Upon completion of the second centrifugation, the supernatant in the 15-mL tube was carefully removed using a Pasteur pipette until a final volume of 0.3 mL of pellet and fluid was left. To this was added 0.1 mL of fresh 5% Lugol's Iodine solution. The tube contents were mixed, and a portion of the cyst suspension was examined using a hemacytometer and binocular microscope. Experiments demonstrated that a diluted volume to 0.4 mL gave the best counting reproducibility.

Laboratory tests were performed to evaluate several aspects of the University of Vermont procedure. The blender method using detergent gave satisfactory results in determinations of cyst recovery when diluted suspensions were prepared as a method check. A study to determine if blending destroyed cysts revealed that the 30 seconds of blending did not result in loss of cysts. An initial concentration of 1.97×10^5 cysts/mL were blended three times for 30 seconds each time. The cysts in the resulting suspension were counted and the count gave a value of 2.20×10^5 cysts/mL.

Four separate experiments were conducted to determine average cyst recovery from the 293-mm membrane filters. Recovery ranged from 50% to 60%. Formalin treated cysts, when stored in distilled water, did not decrease in numbers or show signs of deterioration during two months of storage. Of several different treatments of the cysts after they were in pellet form, staining with Lugol's Iodine was preferred, although use of acridine orange showed some promise for easier cyst identification.

Labelling Procedure

Giardia cysts were labelled with fluorscein (Fluorscein isothiocynate) and Rhodamine (Tetramethylrhodamine-B-isothiocynate) for improved counting and identification. The cysts were labelled in the laboratory and counted for concentration before being applied to the filters under study. This approach was used because the amount of background material interfered with counting and identification of the *Giardia* cysts. The method also improved reliability of results.

The labelling procedure involved preparing 0.5 M carbonate and bicarbonate buffer solutions. These solutions were used to prepare a pH 9 carbonate-bicarbonate solution by titrating the carbonate buffer with bicarbonate to pH 9.

The labelling process involved preparing an ice water-salt bath in which to chill the reaction mixtures. Fifteen mL of cysts resuspended in distilled water were placed in the 50-mL Erlenmeyer flask. Three mL of the carbonate-bicarbonate buffer (0.5 M, pH 9.0) was added. Acetone was then slowly added a drop at a time until 2.4 mL had been applied. The pH of the solution was then rapidly measured and adjusted to pH 9.0 with a few drops of pH 11 carbonate buffer solution or pH 9.0 carbonate-bicarbonate buffer solution. The mixture was chilled thoroughly in the ice water-salt bath and stoppered with a rubber stopper. Fluorscein or Rhodamine (100 mg) which had been dissolved or suspended in 1.5 mL of acetone was then slowly added (Note: Dyes did not always dissolve, but slurry was added as the mixture would go into solution when added to chilled buffered solution.) to the flask. The Erlenmeyer flask and mixture was placed in a rotary shaker overnight and shaken continuously at a temperature of 0-5°C. The next day the mixture was washed with distilled water or any fluid desired for the final cyst concentration, until the supernatant was clear of fluorscein. The procedure outlined is a modification of the procedure for labelling globulin.[24] The amount of fluorscein or rhodamine used (100 mg) was selected in order to have enough dye. The procedure might work satisfactorily with a smaller amount of the labelling compound.

The spiking concentration was prepared from the labelled mixture by centrifugation. The concentration was then made up with 5% formaldehyde to give six screw top test tubes of 4 mL each. Samples were taken from the tubes to determine the concentration and thus the quantity of cysts in the spiking sample. The concentrations provided cyst spiking numbers of 2.1×10^6 to 2.55×10^7 per tube of 4 mL of sample.

Spiking

Giardia cysts were applied to the slow sand filter and the DE filter using spiking techniques and were applied as instantaneous spikes. The cysts were in 20-mL test tubes containing 4 mL of cyst suspension of known cyst concentrations. The tubes were shaken well before the contents were placed in the spiking pump influent container. A funnel and a positive displacement bellows pump were used with hose connections on the discharge end and a funnel on the influent end. The spiking pump hose connection was attached to a threaded sillcock installed in the intake line of the filter, close to the filter. Before placing *Giardia* cysts in the pump intake, the pump system was charged with water, the pump was run for a short period of time to ensure that prime was not lost, and that bubbles did not develop. This flow was followed by the well-mixed *Giardia* sample. The test tube was flushed with water six to nine times then about 1 L of water was flushed through the pump and hose. The spiking rate was conducted at 600 mL/min for 1.5 min.

Sampling

Sampling of filter effluent for cysts consisted of pumping water with positive displacement bellows pumps at about 1 gpm (about 8% of sand filter effluent and 4% of the DE filter effluent) from the test filters to a membrane filter holder equipped with a water meter and pressure gauge. Polycarbonate membrane filters 293 mm in diameter having 5.0 um porosity were used. The meter reading was recorded and timed at the start and at the end of the sampling period in order to determine the volume of water sampled for cysts. Sampler effluent rates were also measured and timed to provide a check on the meter results. Sampling was continued for 24 hr per sample, in the slow sand filter runs, and for the full run duration on the DE filter. Pressure on the influent side of the membrane filter never exceeded 10 psi.

When sampling was completed, all the water in the filter holder was drained by an aspirator. After the top of the holder was removed the surface was washed with about 10 mL of distilled water on to the polycarbonate filter to remove any adhering cysts. The filter membrane was then removed from its holder by means of tweezers, folded to the center to retain any moisture, and placed in a one quart wide mouth mason jar. Adding 50 mL of distilled water to the jar containing the filter membrane was found to be advantageous when reduction of interference from background material was needed. Formalin-fixed cysts did not disintegrate, but some naturally occurring biological materials did . At other times 50 mL of 5% formalin was added. The jars were tightly sealed and shipped in an iced condition to the laboratory for counting. Towards the last half of the Giardia work it was found that 240-mL plastic sample cups worked just as well, took less space, and weren't breakable, so these were used for subsequent sampling and shipping.

Cyst numbers passing through the slow sand filter and the DE filter were obtained by processing the 293 mm sampling filters as described. The cysts from the effluent sampler were concentrated and resuspended to 0.30 or 0.40 mL. Counting was performed in a hemacytometer having a volume of 0.025 mL and thus this provided a multiplying factor proportional to the number of hemacytometer samples counted, resuspension volume, and hemacytometer volume. The hemacytometer count was multiplied by the multiplying factor to give the number of cysts recovered on the effluent sampling filter. Dividing this number by the recovery correction factor (0.433, 97.7% confidence limit) gave the number of cysts in the amount of slow sand filter effluent sampled. Multiplying this number by the ratio of the slow sand filter effluent volume to the sampled volume gave the number of cysts which pass through the slow sand filter (or DE filter) during the sampling time. Example: Spike date 2/28/83, sample date 3/1/83; 321 cysts counted in one hemacytometer sample from a resuspended volume of 0.30 mL, 0.30 ÷ 0.025 x 1 = 12 x 321 = 3852 (number of cysts recovered from the sample filter) ÷ 0.433 x 19440 ÷ 13384 = 124,956 cysts in the effluent. On two other days the cysts were 389 and 2492 producing a total of 131,337 cysts in the effluent for a spike of 2.1 x 10^6 cysts and thus 131,337 ÷ 2.1 x 10^6 = 0.0626 or 6.26% passed through the slow sand filter or 93.7% were removed.

Filter Retention

Giardia cyst removal from cyst spikes was in the order of 99%. There was no indication as to the removal mechanism. In order to try to evaluate the removal mechanism, samples were collected from the sand filter after the long winter spiking run.

Core samples of the filter sand were collected at several spots across the filter, from surface layer to a depth of about 18 in. The samples were collected as layers, 0.5 in., 1 in., 4 in., 7 in., and 6 in. thick. These samples were placed in quart jars, iced, and shipped to the laboratory for cyst evaluation. At the laboratory the samples were stored with 5% formalin and refrigerated.

In order to try to evaluate cyst retention in the filter sand it was necessary to develop a procedure to separate cysts from the schmutzdecke and the sand. Known quantities of cysts were added to some of the core sample sand and procedures studied to recover the cysts.

The first procedure used in attempting to separate cysts from the sand involved mixing the samples with a metal stirrer and pouring off the liquid portion. The remaining settled material was strained through sieves for separating soil particles using either distilled water or formalin with detergent to wash. Sonication was also tried in order to help remove trapped cysts. These experiments yielded a large amount of packed material that was resuspended in various amounts of water. The best amount appeared to be 5 mL. A 0.025 to 0.05 mL sample of the resuspended material was removed and examined under the microscope. Recovery was between 0.007 to 0.03% and there was no significant difference for the sonicated samples. Diluting the samples further did not change the percent of recovered cysts. These results then indicated that another approach was needed for separating the cysts from the background material.

Additional spiked core sand samples were hand mixed with distilled water and detergent. This water was poured off and the remaining sand was vigorously mixed with an electric mixer and the mixture was sieved through a #20 soil filter while washing with more distilled water. The collected filtrate was then passed through a #150 filter to remove small sand particles. The collected filtrate was then allowed to settle over night and the top layer of water removed by suction, 200 mL of water and sediment remaining. This sediment mixture was then spun at 400 g for 15 min and the pellets collected in one tube. This sediment was used in the subsequent experiments to try to separate and concentrate the cysts.

Other approaches used to try to improve recovery of the cysts:

1. Formalin-ethyl acetate separation procedure involving flotation was tried resulting in very little flotation separation.

2. An ion exchange column separation was tried. No significant success.

3. A 1.5 M sucrose gradient separation procedure was tried using centrifugation. The mixture was centrifuged for 30 min at 1000 g. The most promising recovery occurred when the sand/cysts were resuspended in distilled water, but even the best recovery was not satisfactory.

4. An attempt was made to improve recovery by substituting Ficoll in the sucrose gradient procedure. Recovery looked promising, but when conducted on sand samples with full background no separation occurred as the background material seemed to have the same density as the cysts.

5. An electrofocusing apparatus (pH 2 to 10) was used, adjusting to pH 8. Again background material contributed to no recovery of cysts as all material tended to settle to the bottom of the apparatus.

6. A 5-step sucrose gradient procedure was tried (80% to 15% sucrose). This showed some promise, but organic material again interferred.

7. A linear sucrose screen separation was tried using 100 mL of 15% sucrose and 100 mL of 80% sucrose with a separation time of 1.5 hr. Again background floc from the sand samples tended to interfere with the recovery and counting process. Attempts made to dissolve the floc using oxalic acid also gave poor results.

The flocculant material in the sand samples which interferred with all of the separation procedures appeared to be iron and organic materials. No procedure was found which would satisfactorily separate this material from Giardia cysts and without such a separation it was impossible to find cysts under the microscope. This would appear to be a problem which could be encountered whenever cysts are to be separated from sand, sediment, or sludge deposits. No satisfactory solution was found.

BACTERIA

Sampling

Bacterial evaluation was a major concern in all the aspects of this study. Samples were collected as needed from the influent and the effluent streams for the slow sand filter and for the DE filtration process. Sampling frequency varied according to the particular run. During the DE filtration studies 220-mL grab samples were collected about every hour. In the slow sand filter studies a few samples were collected at two to three hour frequencies, but most of the samples were collected at intervals ranging from every one to two days and up to one to two times per month, depending on the particular study. The one to two times per month sampling was utilized to monitor the effectiveness of the slow sand filter over long-time operation.

All bacterial samples were collected in sterile 240-mL plastic sample cups with covers. Each cup was tagged with sample collection information, identification number, and the analysis to be performed. Sample collection information was also recorded in a bacteria log book along with temperature and turbidity values. Samples were collected from faucets or free-flowing pipe discharge streams. All faucets were flushed thoroughly before samples were collected.

Spiking

In order to study the effect of high bacterial concentrations on the respective filters, artificially high bacterial concentrations were provided by using spiking techniques. Bacteria were spiked to the slow sand filter and to the DE filter by means of a 600 mL/min positive displacement bellows pump. The spikes were applied to the influent pipe just before the flow entered the filters. Continuous feed of the sewage spike was provided during the filter run for the particular study. The DE filter runs averaged about 3 hr and the slow sand filter spiking periods were up to 18 days.

The source of bacteria was primary unchlorinated wastewater treatment plant effluent from the St. Johnsbury plant, about 10 mi away. Five-gal plastic jugs were used to collect primary effluent every day when spike runs were underway. Dosing of each batch was continuous over 24 hr when fresh sewage was obtained for the next 24-hr spike dose. Grab bacterial samples were collected from each fresh batch of sewage each day in order to provide bacterial loading information. Correction factor estimates were obtained with respect to storage temperature for the grab sample and 24-hr spiking time. If dilution was utilized, the dilution ratio was recorded, along with data for sampling such as: date, time, volume of sewage pumped. The sewage and sewage spiking tanks were kept in a cool place at all times so that there would be minimal bacterial change during any 24-hr spiking run.

Preservation

The preservation of bacterial samples was accomplished by refrigeration at all times. When samples were collected over a 24-hr period of time, the samples were stored in a refrigerator on-site at 0 to 4°C. If only one set of samples were collected per day, they were collected at a time when they could be shipped immediately to the laboratory by bus.

Shipping containers were commercial styrofoam boxes with close fitting covers enclosed in cardboard protective boxes. Cold packs were kept in the freezing compartment of the refrigerator and were packed in the boxes with the samples with crushed paper keeping the frozen cold packs from contacting the samples. There was a maximum of three hr of travel time from the site to the laboratory. All samples were received in the laboratory and set up for analysis within 24 hr of collection.

Analysis

All bacterial samples were analyzed for total coliform and standard plate count. Dilutions for running the determinations were selected, based on the expected concentrations of organisms. A minimum of two dilutions were used and two complete set-ups were conducted per sample. Two control plates were processed and incubated to establish the lack of contamination of samples by media or handling techniques.

Procedures and media preparation for total coliform were according to Standard Methods.[25] The standard plate count was modified by using the membrane filter technique with M-SPC Medium.[26] Colonies for all filter plates were counted in 24 hr. All dilutions and results were recorded in log books with pertinent sample information.

TRIHALOMETHANE

Sampling for trihalomethane formation was conducted on raw water and slow sand and DE effluent. Summer and winter samples were collected. Collection was in 4-L acid washed glass bottles and transported to the laboratory in iced containers.

Trihalomethane formation was studied for free chlorine residual exposure with a minimum of 10 mg/L residual at the end of 10 days at 20°C. Formation was evaluated for 0, 3, 5, 7, and 10 days of exposure to obtain information on the formation of trihalomethanes with time on the raw water, slow sand filter effluent, and DE effluent.

Initially the chlorine demand of the water was determined following Standard Methods[25] procedure 409A, page 302. From the chlorine demand information chlorine solution (Fisher So-C-70) was added to the samples in the glass sample bottles and thoroughly mixed. Aliquots of the mixture were transferred by siphon to 10 BOD bottles; 2 bottles for each time period. The bottles were stored in a BOD incubator at 20°C for reaction time control. The pH of the mixture was 6.9.

Chlorine residuals were determined for each time period - 0, 3, 5, 7, and 10 days. Residuals were determined by removing 150 mL for chlorine tests (Standard Methods,[25] 408A, page 280) and the remaining 150 mL, the chlorine was neutralized by sodium thiosulphate (Standard Methods,[25] page 486, paragraph 2). After neutralization was confirmed (Standard Methods,[25] page 302, paragraph 3), the remaining water was placed in teflon sealed screw cap vials and identified with exposure time, sample number, and date. These vials were then stored under refrigeration for gas chromatographic (GC) analysis for chloroform, bromoform, chlorodibromomethane, and bromodichloromethane. Methyl chloroform was also checked on some samples.

The trihalomethane determinations were performed using a gas chromatograph with an electron capture detector using Ni-63 foil. The purge and trap procedure in Standard Methods[25] (page 538), 514, Halogenated Methanes and Ethanes by Purge and Trap (Tentative) was used to determine THM values.

TURBIDITY

Monitoring

Turbidity measurement was the primary monitoring parameter for the slow sand and DE filters. The principal observations were obtained from the laboratory turbidimeter located in the on-site laboratory trailer. The slow sand filter influent and effluent were monitored continuously by Hach low-range turbidimeters, model 1720A with recorders. The laboratory turbidimeter was a Hach ratio turbidimeter, model 18900 and in addition to frequent formazine standardization (average of every 5 mo) daily checks were made with the Hach permanent standard suspensions.

Laboratory

Laboratory turbidimeter data were obtained by sampling the influent and effluent of the slow sand filter on a daily basis. The DE filter samples were collected regularly during the time the filter was in operation, usually when bacteria samples were collected. Turbidity values were determined on the laboratory turbidimeter as soon as samples were collected with time allowance for temperature adjustment.

The laboratory instrument provided the principal turbidity data for this work. The flow-through monitoring turbidimeters did not provide reliable data for this water. Slime growths tended to build up and interfere with operation. Cleaning twice a day and calibration every two weeks might have produced reasonably accurate results. However, the effort which would have been required was not worth the questionable data since dependable results were being obtained by the daily sampling and laboratory turbidimeter readings. Continuous but relative flow-through records were kept. Frequent cleaning, particularly of the influent sampling line, provided some relative values on an hour by hour basis.

TEMPERATURE

Values for temperature were obtained and recorded daily for the influent and effluent streams of the slow sand filter and also the air temperature. The DE filter temperatures were virtually the same as the raw water temperature and the daily value obtained for the slow sand filter could be used for the DE runs.

The slow sand filter temperatures were obtained by using mercury thermometers in the continuous flow line from the monitoring turbidimeters. This approach eliminated any need for a stabilization time for making readings. The thermometers used to record water temperatures were calibrated against a standard thermometer and the variations were so close there was no need for adjustment of temperature readings. Air temperature readings were also recorded using a commercial outdoor thermometer. Calibration of the outdoor thermometer indicated a constant 2°C reading above the standard reference thermometer. No corrections were provided as the air temperature during the day varied by much greater values than the 2° reference error. An instantaneous air temperature reading is only a relative indication of air temperature for the day of reading.

PARTICLE COUNTS

Sampling

Samples for particle concentration determinations were obtained from the bacterial samples collected in sterile plastic cups. Two 240-mL samples were collected for the bacterial sampling whenever it was thought that the bacterial levels might be low and thus a larger sample might have to be utilized. This extra sample ensured that there was enough sample for particle determinations.

Particle counts were conducted on the samples within 12 hr of delivery to the laboratory (providing a maximum holding time of 14 hr). The particle determinations were obtained by means of a Coulter® counter. The values obtained were for the number of particles in the sample in the 7 to 12 µm range. At the start of the project, the lower limit had been 5 µm, but this was changed to the 7 µm lower size limit as this had been shown to provide a closer approximation to *Giardia* cyst sizes.[20]

The particle samples were preserved in the same manner as the bacterial samples. During shipping the samples were packed with ice. In the laboratory the samples were stored at 0 - 4°C at all times until analysis was performed. Particle samples were not allowed to stand for a prolonged period of time before analysis in order to ensure that settling would not affect the results. All samples were thoroughly agitated before particle testing to ensure that the integrity of the sample was preserved.

The particle determinations were obtained from a model MHR Coulter® counter. In using the counter the stored samples (refrigerated) were shaken for 1 min to ensure uniform distribution of particles. A 10-mL sample was removed from the resuspended sample and mixed with 10 mL of normal saline solution. A 0.1 mL portion of this dilution was aspirated by the automatic sampling aspirator into the counting chamber. The initial minimum aperture was set at 7 µm. Three or more readings were taken to obtain values or until steady results were obtained. A dependable span of counts was always obtained within five minutes. The instrument was then reset to a minimum aperture of 12 µm and a second set of readings obtained following the same procedure. These two readings provided particle information for sizes greater than 7 µm and the second reading for particles greater than 12 µm. The particle counts were calculated by averaging the readings and subtracting the difference to obtain the particles in the range of 7 to 12 µm, correcting for the saline dilution.

The Coulter® counter was calibrated daily against a second instrument. Standard particle size suspensions were used for standardization checks every month. A typical count is shown in Table 5.

TABLE 5. COULTER® COUNTER PARTICLE DETERMINATIONS - PARTICLES IN SAMPLE GREATER THAN APERTURE SETTING

	7 µm Aperture No./mL		12 µm Aperture No./mL
	1460		1000
	1500		1010
	1480		1020
Avg.	1480	Avg.	1010

Calculation:
7-12= 1480-1010= 470 X2(2X dilution with saline) = 940 (7-12u) COUNT = 940

QUALITY CONTROL

Quality control procedures were developed to ensure that variations in the data did not develop in laboratory analyses and reported results which were the result of errors in equipment, sampling, observation or laboratory analyses. Bound data books were used to record all information in the field and laboratories. Field personnel maintained activity log books with appropriate notations. Field data included date, time, person, temperatures for air and raw water and effluent, raw and effluent turbidity using Hach model 18900 ratio turbidimeter, head loss, effluent flow measurement, plant operation, filter cleaning, chlorinator operation, and appropriate remarks. Black waterproof pens were used to record all information in the data books.

Slow Sand Filter

The slow sand filter used for this field research was an existing structure and thus there was no direct control over the sand placement, retaining wall construction, and other control criteria normally considered desirable in insuring that the filter would not have any serious shortcomings or possible short-circuiting[27-30]. In order to evaluate the integrity of the filter a flow-through or retention time evaluation was made.

The retention study consisted of injecting a concentrated sodium chloride solution into the filter intake (filtration rate 0.08 m/hr) and measuring the conductivity in the effluent from the time of salt spiking to the time the effluent returned to the background conductivity. Figure 4 shows the results of this study. This figure shows that no apparent gross short-circuit existed in that more than 4 hr was required before the background conductivity changed to a conductivity affected by the injected salt. However, complete plug flow at a filtration rate of 0.08 m/hr would have taken about 22.9 hr whereas the measured centroid of the area above background was 11.7 hr, indicating a hydraulic shortening of the flow through the filter. The time to return to background was 56 hr and thus there was also considerable drag-out of the spike. This indicates that 50% of a spike application could be expected to flow through the filter in 11.7 hr and 90% in 30 hr if other spiked materials would respond in the same manner.

The time for return to background was 56 hr. Most of this short-circuiting effect and drag-out would be expected to occur in the 4.5 ft of water above the sand and not in the sand bed itself.

The results of this evaluation indicate that there was reasonable integrity of the slow sand filter under field operation conditions.

Giardia

No standards or standard procedures have been established or are available from any monitoring organization for the *Giardia* cyst analysis. Repetition was the primary method of insuring the quality of results along with some control tests. The quality assurance emphasis was primarily on the recovery of a known number of cysts from the 293 mm membrane sampling system and the reproducibility of counts from the sample filters using fluorescent dye treated cysts.

Four recovery studies were conducted using the *Giardia* field sampling equipment. Known concentrations of cysts were mixed with water and pumped through the sampler system and filter. The filter was removed as described for field sampling and the recovered cysts counted using a hemacytometer. Results are shown in Table 6.

TABLE 6. *GIARDIA* CYST SAMPLER RECOVERY

Cysts Applied/mL	No. Slides	No. Squares	Recovery Concentration	Recovery Percent
3.5×10^5	2	5	1.82×10^5	52.0
3.5×10^5	2	5	1.72×10^5	49.1
5.2×10^5	2	5	3.21×10^5	61.7
5.2×10^5	2	5	3.16×10^5	60.8

Average recovery from the sampler filter was 55.9%. This figure also served as a correction factor in calculating the number of cysts in the effluent being sampled. The final correction value used was 45% as the 97.7% confidence limit value based on a statistical distribution of recovery results.

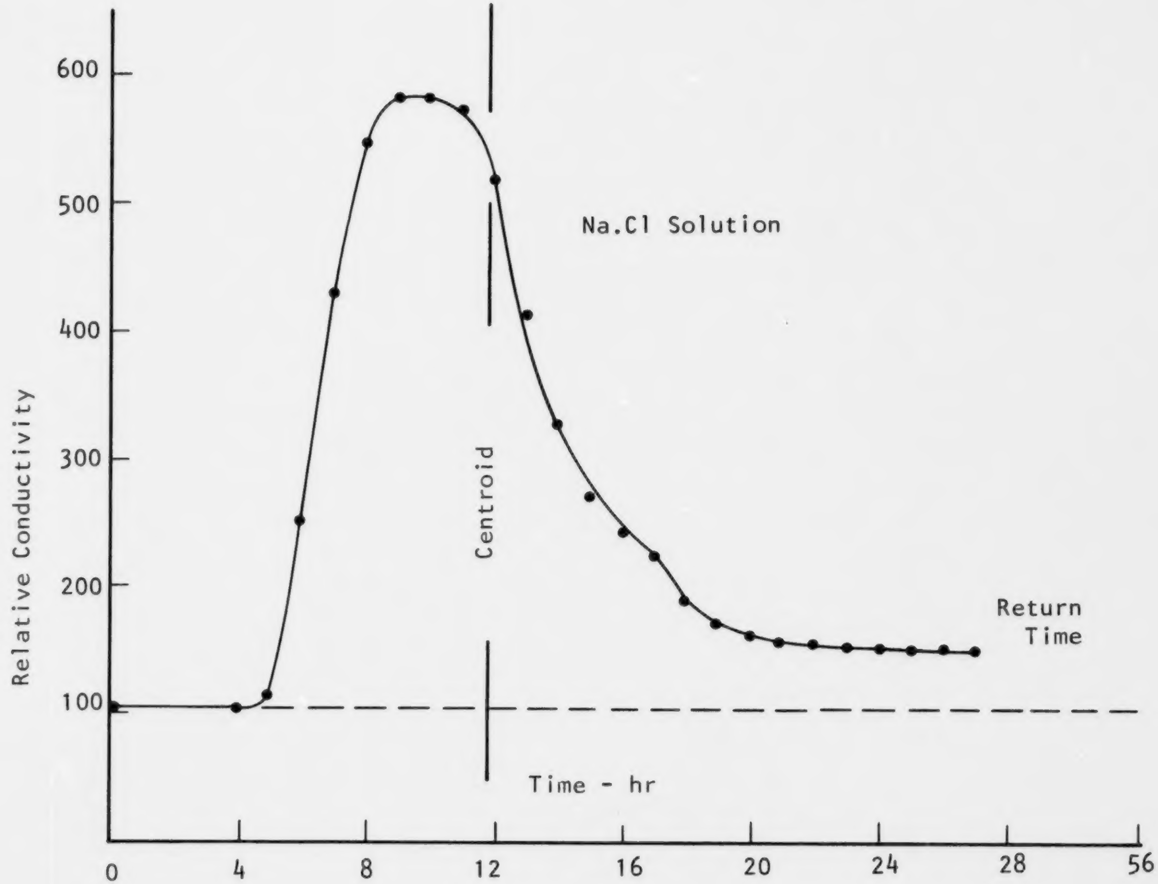


Fig. 4. Relative Conductivity vs Flow, Residence Time - Slow Sand Filter - Filtration Rate 0.08 m/hr

When slow sand filter effluent samples were counted, three separate hemacytometer counts were performed on each sample. To obtain better counts and to indicate the reliability of the first three hemacytometer counts another separate set of three counts from the same sample were obtained from at least one sample from the first five samples collected after a Giardia spike was applied to the filter. This separate duplication of the three hemacytometer counts was made about the third day after spiking. This approach was selected because most of the cysts were found to appear in the samples within about 5 days.

When sampling was conducted for more than 5 days, the six hemacytometer count sequence was performed on about every fifth sample after the initial start. The results of a six-count sequence are shown in Table 7.

Bacteria

The total coliform bacterial analysis was performed according to Standard Methods[25] and the standard plate count was conducted using the filter technique and M-SPC media described by Taylor and Geldreich.[26] Most bacterial analyses were performed within 30 hr of sampling except for 15 out of 485 samples. If samples were not run immediately upon receipt at the laboratory they were stored under refrigeration at 0-4°C. The elapsed time between collection and laboratory analysis for total coliform and standard plate count for 485 samples was a mean of 13.7 hr, maximum of 44 hr, and a minimum of 1 hr.

Dilution water sterility checks were run weekly by filtering sterile dilution water through the filters and incubated with media. Each batch of medium was checked for sterility by saturating filter pads with the medium and incubating for 24 and 48 hr. Whenever positive results were obtained the media was discarded and new media prepared, which only occurred once for the 23 standard plate count checks (M-SPC) and none for the 29 total coliform checks (M-EndoBroth MF). This determination was made each time coliform and standard plate count samples were run. Dilution water pH and incubation temperature values are summarized in Table 8 for both total coliform and standard plate count analyses.

Every time samples were run negative control plates were also prepared using the dilution water by setting up membranes and running the dilution water through the membranes and culturing on media. Positive control plates were also performed from time to time to ensure that positive growth did occur and thus that the media would produce growth in the presence of bacteria. The positive controls were developed by spiking the dilution water with a water source known to contain live bacteria (influent from sewage treatment plant). Results of these tests are summarized in Table 9.

TABLE 7. GIARDIA COUNT REPRODUCIBILITY

	Counts/Sample				
Sample No.	First Three Counts	Calculated Number	Second Three Counts	Calculated Number	Calculated Six Count Number
12-9-83	140	746	143	762	756
12-14-83	19	101	19	101	101
12-20-83	3	16	1	5	11
12-25-83	0	0	0	0	0
12-30-83	0	0	0	0	0
1-8-84	0	0	1	5	3
1-14-84	0	0	0	0	0
1-18-84	283	1508	370	1972	1744
2-3-84	1	5	2	11	8
2-8-84	0	0	0	0	0
2-13-84	0	0	0	0	0
1-23-84	0	0	0	0	0
1-30-84	3	16	1	5	11
2-18-84	31	165	24	128	147
2-24-84	2	11	1	5	8
3-11-84	1	5	0	0	3
3-17-84	6	32	1	5	19
3-26-84	1	5	2	11	8
4-5-84	4	21	6	32	27
4-12-84	0	0	0	0	0
4-18-84	0	0	0	0	0

NOTE: Pellet Dilution 0.40 mL for all samples

TABLE 8. pH AND INCUBATION TEMPERATURE

Parameter	Number of Observations	Results Average	Maximum	Minimum
Total Coliform				
pH Dil. Water	27	7.14	7.2	7.1
Incubation Temperature	28	35.0	35.5	34.5
Standard Plate Count				
pH Dil. Water	23	7.14	7.2	7.1
Incubation Temperature	23	35.0	35.5	34.5

TABLE 9. MEDIA AND DILUTION WATER CONTROL CHECKS

Parameter	Number Observations	Growth Number+	Growth Number-
Total Coliform			
Negative Control	575	0	575
Positive Control	13	13	0
Standard Plate Count			
Negative Control	617	2	615
Positive Control	9	9	0

Trihalomethanes

The THM precursor studies depended on free chlorine residual and THM determinations. Chlorine residuals were measured when applying chlorine to raw water and effluent samples and at the respective reaction time intervals.

Standard chlorine check samples were analyzed in the EPA Quality Control check program. Results of these check samples are shown in Table 10. All of the free chlorine results fell within the acceptable limits.

The THM determinations were performed by an EPA approved Analytical Service Laboratory (ASL) for THM determinations. The laboratory participated in their own quality control check sample program and in addition samples for this project. The results of these checks are shown in Table 11. Some individual THM and some TTHM values fell outside the acceptance limits. Rechecks were made and all values fell in the accepted limit range.

Turbidity

Raw water and effluent was monitored by both the Hach ratio turbidimeter and the model 1720 flow-through turbidimeters (slow sand filter only). Initially on installation all turbidimeters were calibrated with formazine solution following the manufacturer's manual.

For the laboratory ratio turbidimeter the permanent standard values were recorded at the start and whenever formazine standardization was performed. The results for these determinations are shown in Table 12.

Calibration was performed on the average of every 5.4 mo with a minimum of 4.4 mo and a maximum of 6.7 mo.

TABLE 10. QUALITY CONTROL CHECKS - EPA STANDARDS - FREE CHLORINE

Sample Number	Measured Value (mg/L)	True Valve (mg/L)	Acceptance Limits (mg/L)
WS009-1	.88	.95	.65 - 1.3
WS009-2	1.11	1.20	.87 - 1.6
WS010-1	.89	.70	.42 - .99
WS010-2	1.73	1.51	1.2 - 1.8
WS012-1	.25	.325	.0659 - .565
WS012-2	.95	1.08	.595 - 1.41
WS013-1	.35	.606	.35C - .835
WS013-2	1.05	2.16	1.56 - 2.82

Standard turbidity check samples were analyzed in the EPA quality control check program. The results of these check samples are shown in Table 13. All of the turbidity results fell in the acceptable range and many times they were equal to or within 0.10 NTU.

The Hach® 1720 turbidimeters were installed with strip chart recorders and observations were maintained and recorded for the initial period of time. However, data from these turbidimeters became questionable because of difficulty in operation and maintenance. The characteristics of the water were such that slime growths would plug the raw water turbidimeter within a few days and would within one day affect the determinations. In order to obtain results which would appear to have any validity would have required cleaning the raw water turbidimeter a minimum of one to two times per day and the effluent turbidimeter at least one time per week. Performance was so variable it was felt that the extreme amount of maintenance and work effort required could not be justified to obtain the data since the effluent samples were being checked each day with the laboratory ratio turbidimeter. The flow-through turbidimeters were kept on line with recording charts throughout the project in order to give some indication of daily variations, but the results were not used for any meaningful or reliable data.

Temperature

Thermometers used in the treatment plant and Giardia storage activities were evaluated for accuracy by checking them against a mercury reference thermometer which had been standardized against a standard reference thermometer. The standard reference thermometer was a long-stemmed glass mercury thermometer, Fisher® 15-0435 (783-091), 0-100°C. This thermometer was used to standardize a glass reference thermometer which served as a secondary standard (Fisher®, mercury). Calibration for the secondary reference thermometer is shown in Table 14.

TABLE 11. PERFORMANCE EVALUATION - TRIHALOMETHANE

Sample Number	Measured Value (µg/L)	True Value (µg.L)	Acceptance Limits (µg/L)	Measured Value (µg/L)	True Value (µg/L)	Acceptance Limits (µg/L)
		CHLOROFORM			BROMOFORM	
WS009-1	27	25.5	2.0 - 31	11	11.0	8.3 - 13
WS009-2	116	102	82.0 - 120	64	65.8	53 - 79
WS010-1	56	61	49 - 74	84	82	66 - 99
WS010-2	17	20.4	16 - 24	21	21.9	18 - 26
WS010-1	4.8	5.93	4.74 - 7.12	24.4	30.5	24.4 - 36.6
WS012-2	32.8	35.6	28.5 - 42.7	63.2	67.7	54.2 - 81.2
WS013-1	77.3	71.2	57.0 - 85.4	55.1	50.8	40.6 - 61.0
WS013-2	46.0	23.7	19.0 - 28.4	28.4	27.1	21.7 - 32.5
WS879-1	11.8	10.7	6.1 - 15.4	13.0	12.1	7.4 - 17.1
WS879-2	64.8	75.1	38.5 - 101.6	3.9	3.5	1.0 - 6.0
		BROMODICHLOROMETHANE			DIBROMOCHLOROMETHANE	
WS009-1	17	13.7	11 - 16	20	5.92	4.7 - 7.1
WS009-2	57	59.3	47 - 71	94	88.9	71 -110
WS010-1	63	73	58 - 88	54	53.3	43 - 64
WS010-2	24	27.4	22 - 33	25	23.7	19 - 28
WS012-1	14.9	14.1	11.3 - 16.9	28.2	27.9	22.3 - 33.5
WS012-2	45.1	42.3	33.8 - 50.8	58.8	55.8	44.6 - 67.0

TABLE 11. (continued)

Sample Number	Measured Value (µg/L)	True Value (µg.L)	Acceptance Limits (µg/L)	Measured Value (µg/L)	True Value (µg/L)	Acceptance Limits (µg/L)
	BROMODICHLOROMETHANE			DIBROMOCHLOROMETHANE		
WS013-1	62.3	56.4	4.51 - 67.7	43.6	39.0	31.2 - 46.8
WS013-2	23.9	18.8	15.0 - 22.6	13.0	11.2	8.96 - 13.4
WS879-1	5.0	4.5	.77 - 8.2	5.6	6.3	2.7 - 10.2
WS879-2	18.6	18.7	11.5 - 25.5	14.6	18.9	10.7 - 26.6

TOTAL TRIHALOMETHANE

Sample Number	Measured Value (µg/L)	True Value (µg/L)	Acceptance Limits (µg/L)
WS009-1	75	56.12	44.5 - 67.1
WS009-2	331	316	253 - 380
WS010-1	257	269.3	220 - 320
WS010-2	87	93.4	75 - 110
WS012-1	72.3	78.43	62.74 - 94.12
WS012-2	199.9	201.4	161.1 - 241.7
WS013-1	238.3	217.4	173.9 - 260.9
WS013-2	111.3	80.8	64.66 - 96.9
WS879-1	35.4	33.6	16.97 - 50.9
WS879-2	101.9	116.2	61.7 - 159.7

TABLE 12. HACH® RATIO TURBIDIMETER CALIBRATION

Date	Permanent Standards 1.8	18	180
03-23-82	1.70	17.6	186
08-4-82	1.66	16.7	180
02-25-83	1.59	15.9	168
08-16-83	1.59	16.6	178
01-4-84	1.83	18.0	168

TABLE 13. QUALITY CONTROL CHECKS - EPA STANDARDS
Turbidity

Sample Number	Measured Value (NTU)	True Value (NTU)	Acceptance Limits (NTU)
WS009-1	0.95	1.0	0.63 - 1.3
WS009-2	6.78	6.7	6.1 - 7.3
WS010-1	1.29	1.35	0.95 - 1.7
WS010-2	5.50	5.5	4.6 - 6.4
WS012-1	5.55	5.9	5.20 - 6.62
WS012-2	0.37	0.42	0.184 - 0.655
WS013-1	6.00	6.00	5.47 - 7.35
WS013-2	0.66	0.70	0.456 - 1.15

TABLE 14. REFERENCE THERMOMETER CALIBRATION - °C

Standard	Reference	Difference
40.4	40.2	-0.2
23.2	23.5	+0.3
22.0	22.2	+0.2
15.8	15.3	-0.5
7.6	7.7	+0.1
4.3	4.0	-0.3

The thermometers used for measuring the water temperature were calibrated against the reference as shown in Table 15.

TABLE 15. WATER PLANT THERMOMETER CALIBRATION - °C

Reference	Effluent	Difference	Influent	Difference
25.1	25.1	0	25.5	+0.4
19.1	19.1	0	-	-
16.5	-	-	16.8	+0.3
15.8	15.8	0	16.0	+0.2
9.5	9.5	0	10.0	+0.5
5.0	4.5	-0.5	5.0	0
-2.0	-2.8	-0.8	-2.0	0

The Giardia storage thermometers were standardized against the standard reference thermometer and the calibration is shown in Table 16.

The calibration readings of the storage thermometers were used to regulate the temperature in the refrigerators based on the calibration correction and more accurate thermometers were not obtained.

TABLE 16. GIARDIA STORAGE THERMOMETER CALIBRATION - °C

Standard	Refrigerator	Difference	Outdoor	Difference
3.0	3.3	+0.3	4.0	+1.0
21.1	21.1	0	20.0	-1.1

Particle Counts

Particle determinations were made under test conditions which would produce constant averaged readings. Results were obtained by performing several analyses on each sample. Table 17 and 18 summarize the number of analyses on each sample. Table 17 shows the minimum number of counting runs on a sample to provide a counting average. This shows that 284 of the 490 samples involved a minimum of 4 analyses or more on each sample for at least one of the aperture settings (7 µm or 12 µm). The results for only 24 samples were obtained by performing 3 or fewer analyses. In Table 18 the analyses conducted at each aperture are summarized. This shows that for 218 samples the greater than 7 µm aperture reading was analyzed four times and only 17 samples were tested with 3 or fewer analyses. At the greater than 12 µm aperture 265 sample determinations were made with 4 analyses and only 17 sample values were obtained by 3 or less analyses per sample.

The Coulter® counter was checked against another counter and also the counter was standardized monthly with a standard count solution supplied by the manufacturer. This was performed 17 times during the project period.

TABLE 17. PARTICLE COUNTS - MINIMUM ANALYSES TO PROVIDE A DETERMINATION

Minimum Number Analyses/Sample	Number of Samples
2	1
3	23
4	284
5	122
6	51
7	6
8	2
12	1
	490

At times there was some delay between sample collection and counting. Fifty percent of all samples were analyzed within 60 hr. A study was conducted to evaluate the effect of storage on the count results. Influent and effluent samples from the slow sand filter were collected and stored under refrigeration and counts made at specified intervals. Each sample was split into eight sample cups to provide a portion for each counting test. The results are shown in Table 19. This shows some variation with time but no real trend. This evaluation was rechecked using the same sample container for all eight determinations.

TABLE 18. PARTICLE COUNTS - NUMBER OF ANALYSES/APERTURE TO DETERMINE AVERAGE FOR SAMPLES

Number Analyses/Sample	No. Samples per Aperture 7µm	12µm
2	1	---
3	16	17
4	218	265
5	129	118
6	77	66
7	23	11
8	17	9
9	5	3
11	1	---
12	2	---
16	1	---
21	---	1

TABLE 19. EFFECT OF STORAGE TIME ON PARTICLE COUNTS (SLOW SAND FILTER)
PARTICLE COUNTS - 7-12 μm

Date	Time	Elapsed Time (hrs)	Particle Count (No./1 mL) Influent	Effluent
		First Evaluation		
8/8/83	1335	0	---	---
8/8/83	1530	1.92	4020	1650
8/9/83	0820	18.8	3390	1110
8/9/83	1500	25.5	2330	2700
8/10/83	0800	42.5	2140	4260
8/10/83	1500	49.5	2490	1850
8/11/83	1440	73.2	2070	1540
8/14/83	1500	145.2	3960	1310
		Second Evaluation		
11/24/84	1115	0	---	---
11/24/84	1500	3.8	20860	18600
11/13/84	0830	21.3	30110	13650
11/13/84	1500	27.8	32750	20150
11/14/84	0930	46.3	25450	23200
11/14/84	1445	51.5	31090	30080
11/15/84	0845	69.5	38320	31940
11/15/84	1500	75.8	30800	21460
11/16/84	0930	94.3	41790	31400
11/16/84	1530	100.3	43880	31630

It appears that the first test series provided variations mostly caused by sample splitting. The second evaluation showed some trend of growth with time. The slime organisms are suspected because they were reported to clog the counter from time to time. Growth may not have been so obvious in the first analysis because raw water temperature was about 20°C and refrigeration temperature might have inhibited organisms' growth. Water temperature for the recheck was about 6°C (about refrigerator temperature) and the organisms would have been well acclimated and growth would increase the count results with time. The general effect was that there was either no appreciable change in count with time or there was an increase. There was no evidence of a loss of count results with time.

Flow

Measurements of flow involved the slow sand filter, DE filtration and the *Giardia* sampler.

Slow sand filter effluent flow checks were observed every day and timed-volume checks (16 seconds per bucketful) were made by the operator and/or the field personnel a minimum of three times per week. Flow adjustment was made when the flow varied from the 16 seconds ± 3 seconds or when timed-weight measurements indicated that the flow rate needed adjustment.

Timed-weight measurement was the primary calibration control and was used every time the filter was started up, whenever major corrections were made or as an interim check of timed volume flow measurements. Timed-weight flow checks were conducted 51 times on the slow sand filter discharge during the project. The mean of the measured flow was 13.4 gpm with a standard deviation of 1.7 gpm.

The desired flow was 13.5 gpm (filtration rate 0.8 m/hr) and the mean of 13.4 very closely approached the desired value. There were some variations because of manual control conditions. Weight-timed volume flow checks were made 41 times between 5/27/82 and 4/30/84 or an average of every 17 days.

Flow from the DE filter during operation was measured by means of a water meter and was checked by timed-weight measurements. The water meters used in the project were calibrated for flow correction and the calibration is shown in Figures 5 and 6.

Flow from the Giardia sampler was measured to obtain the volume of sample collected from the effluent. The flow was measured by a water meter and monitored by timed-volume checks. The water meter calibration for the Giardia sampling is also indicated in Figures 5 and 6 for timed-weight calibration, particularly Figure 6. These results provided correction factors when calculating sampling amounts.

The water meter tended to malfunction at times during Giardia sampling. To ensure that flow data was recoverable the sampler was also checked by timed-volume flow and compared with the meter reading. Results of the timed-volume flow measurement were used to calculate corrected flow when it appeared that the meter was not properly indicating. Positive displacement pumps were used in pumping samples through the sampler and thus this provided consistent flow on a day to day basis. The capacity of the pumps did tend to decrease slowly with time but did not vary rapidly from one day to another. An electric clock was connected to the circuit used to provide electricity for the pumps. If a power outage and associated shut-down of the sampling pumps occurred, correction could be made for such an event by adjusting for the number of minutes when the pumps did not operate.

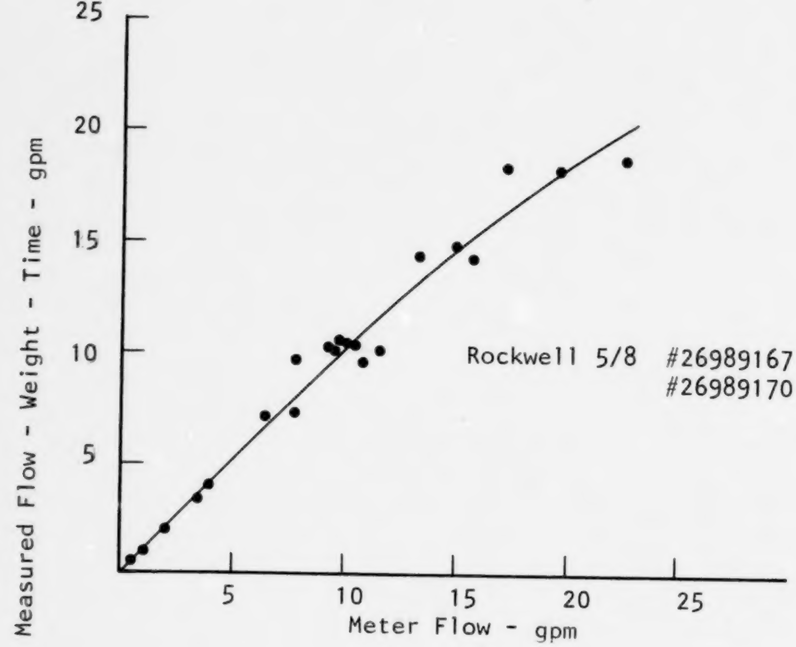


Fig. 5. Calibration of Water Meters

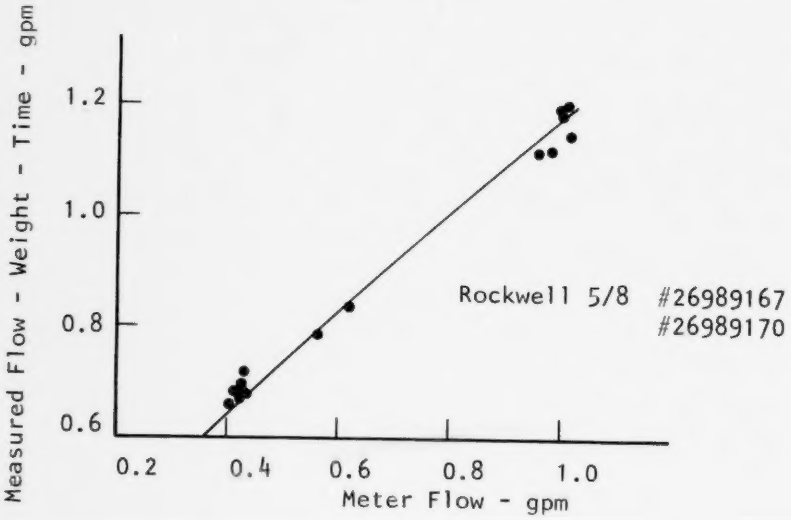


Fig. 6. Calibration of Water Meters at Low Flow Rates

SECTION VI

RESULTS AND DISCUSSION

RAW WATER

Quality

The quality of the raw water from the source of supply was initially described in Table 1, page 12. This predesign data was augmented with intake sample test results shown in Table 20.

These analyses provided indications of the characteristics of the water as well as the effect of the marble prefilter inlet system. The results indicated that the water was still relatively satisfactory as a raw water supply. The values agreed well with the predesign data in most instances.

TABLE 20. RAW WATER CHARACTERISTICS (2/16/82)

Characteristic	Stream	Slow Sand Filter Intake
Total Particle Count (5-15 um)	5420/1 mL	2580/1 mL
Color (SU)	5	5
Turbidity (NTU)	1.6	1.23
Iron*	0.13	0.05
Chlorides	3.0	3.0
Manganese	0.03	0.02
Calcium	21.1	21.4
Hardness**	38.4	43.6
Alkalinity**	8.82	8.33
Total Plate Count, per 100 mL	10	10
Total Coliform, per 100 mL	5	5
Nitrates-N	0.11	0.14
Nitrite-N	.02	.02
Total Kjeldahl Nitrogen	56.0	17.0
Ammonia Nitrogen	25.0	7.0
Sodium	1.5	149.0
Suspended Solids*	1.0	1.0
pH (SU)	7.05	7.05

*Values for iron through Suspended Solids are in mg/L.
**Hardness and alkalinity expressed as mg/L of $CaCo_3$

The prefilter did appear to modify the supply by reducing particle counts in the order of 50%, turbidity reduction appeared to be minimal, iron was reduced by about 50% or more and organic material was reduced as indicated in the reduction of the total Kjeldahl nitrogen and ammonia nitrogen values. The fairly high values of total Kjeldahl nitrogen and ammonia nitrogen indicated that there was a fairly large amount of organic material and nutrients available in the water. The other parameters did not appear to be affected significantly by the intake filter structure although hardness may have been increased slightly.

The sodium value in the raw stream water appeared to be much lower than expected as it was much lower in value than any results in the predesign data or even for the raw water value after the inlet structure. Rechecks shown in Table 21 indicate that sodium values appear to be variable depending on the time of year sampled. Road salting may produce an effect on the sodium concentrations, as shown in Tables 1 and 21.

TABLE 21. SODIUM IN RAW WATER (mg/L)

Date	Stream at Intake	Filter Influent
9/13/84	2.38	----
9/20/84	2.36	----
10/10/84	2.21	2.26
10/22/84	2.30	2.30

The raw water turbidity at the inlet to the slow sand filter is summarized in Table 22 for 674 observations. These results indicate that the source was satisfactory for slow sand filter treatment most of the time. The average value of 1.4 NTU during the study is rather low considering that there were some fairly high values from time to time; the maximum value was 59, the minimum, 0.2. In some ways these values were extremely low considering the wet land nature of the impoundment.

TABLE 22. RAW WATER TURBIDITY AT SLOW SAND FILTER INTAKE

Turbidity, NTU	Number of Observations	Percent
Above 3.0	57	8.5
2.1 - 3.0	57	8.5
1.1 - 2.0	226	33.5
0.5 - 1.0	324	48.0
Below 0.5	10	1.5

The high turbidity values were mostly the result of rain storms or melting snow. In the summer of 1983 the raw water turbidity tended to be higher than it was during the previous summer because of road work on a culvert between the upper and lower impoundments. This work affected the raw water turbidity for about 4 months, from July to the end of October. However, the turbidity was not so high that there were any significant operation problems or observable shortening of filter runs. The filter continued to be able to produce water with less than 1 NTU. The values averaged 5 to 8 NTU during the construction rather than the 1 to 2 NTU previous to the construction work.

It appeared that there was a possible seasonal trend to the raw water turbidity. The values tended to be higher in the summer than the winter. This variation with season could be described as being higher than average from the first of July to the end of October or November. There was a considerable amount of variation in values from day to day. The variation also tended to be more pronounced in summer than in winter. Most of this variation could be attributed to natural winter effects such as limited biologic activity, ice and snow cover preventing wind disturbances, and reduced runoff from precipitation. However, with all the variations and construction impact 83% of the observed values were 2.0 NTU or less, a fairly low turbidity for raw water.

The raw water turbidity also tended to show a variation with temperature. A close correlation could not be developed for the two-year period of observation because the construction work contributed to high turbidity when the turbidity values would also have tended to be high if responding to temperature. Also, after the construction the high raw water turbidity was more persistent during the time the water temperature was cooling down in the fall than had been observed the previous year.

Bacteria

The raw water bacterial characteristics are shown in Table 23 which summarizes the characteristics for the standard plate count and the total coliform. The numbers were not excessive much of the time but were challenging for slow sand filter treatment. There was considerable variation in concentrations from time to time.

TABLE 23. RAW WATER BACTERIA

	Standard Plate Count, mL	Total Coliform, 100 mL
Number of observations	209	209
Average	185	296
Maximum	5100	8700
Minimum	1	1

The standard plate count was moderate for a surface drinking water but there were some rather high contributions. Such high values could be the result of human activity in the drainage basin and the impoundment and also erosion action caused by natural phenomena such as rain storms. The organic sediment on the impoundment bottom would support many types of bacteria.

High or low standard plate count appeared to be related to the weather conditions and snow cover. The values tended to be highest in the months of May, July, August, and September (500/mL or more) with one high value in January (January thaw) and one in March (start of spring runoff). The rest of the time the values were below 500/mL and usually about 100/mL.

The total coliform values are also in a challenging range for slow sand filter treatment with some very high contributions. It could be expected that there would be a fairly high coliform concentration since there are roads and human activity in the drainage basin and through the impoundment. In addition to humans being present in the area, wild animals such as deer, bear, and particularly beaver, muskrats, and water birds had access to the water. These animals and birds would contribute coliform directly and also the extensive amount of organic sediments could support the organism.

Table 24 and Figure 7 summarize the distribution of the raw water bacteria results with respect to the number of samples reported. This table and figure show that 50% of the time the raw water standard plate count was less than 73/mL and the total coliform was less than 90/100 mL. Figure 7 also indicates that over the long run the standard plate count and total coliform concentrations appeared to be related and thus the impoundment sediment would appear to be the major contributor of bacteria in the higher ranges. The change of the relationship shown in Figure 7 for total coliform and standard plate count in the lower range indicates that about 30% of the time lower coliform counts are the result of other bacterial activity, probably rapid coliform die-off or reduction in the sediments.

TABLE 24. RAW WATER BACTERIAL RANGES

	Standard Plate Count (No./mL)		Total Coliform (No./100mL)	
Range	Number of Observations	Percent	Number of Observations	Percent
0-9	10	4.8	29	13.9
10-49	72	34.4	41	19.6
50-99	49	23.4	41	19.6
100-199	30	14.4	37	17.7
200-499	34	16.3	38	18.2
500-999	11	5.3	11	5.3
1000-4999	2	0.9	10	4.8
5000-Above	1	0.5	2	0.9
Total	209	100	209	100

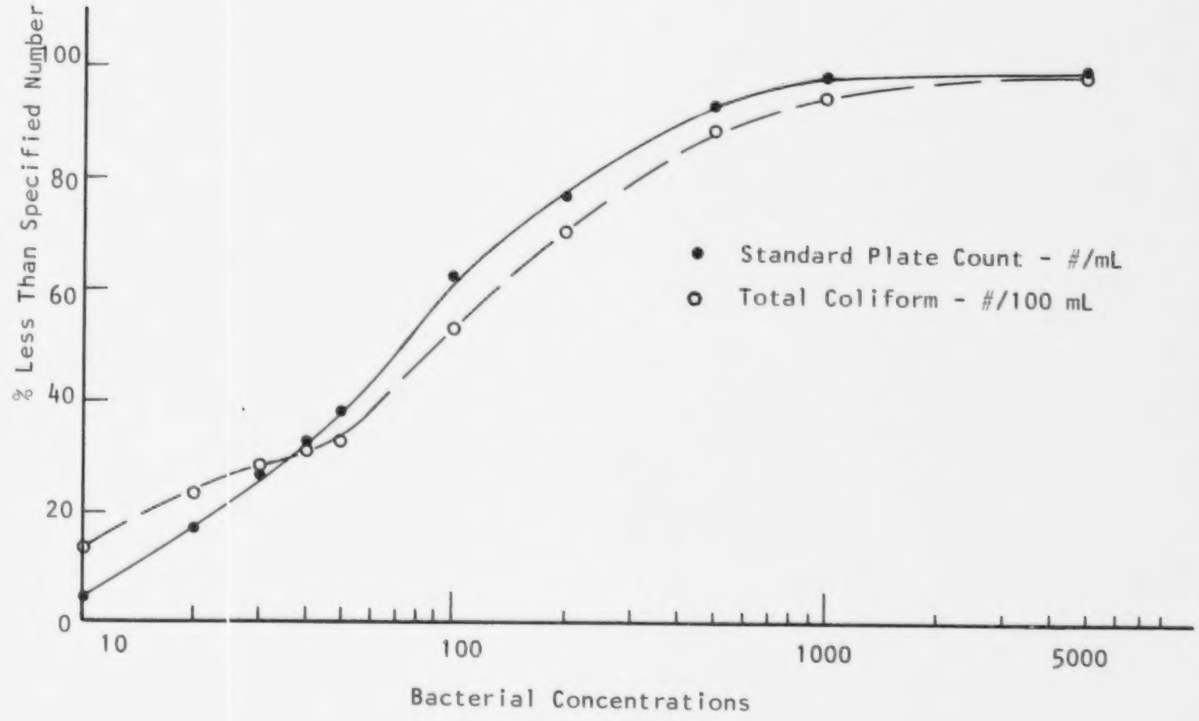


Fig. 7. Observed Occurrence of Bacterial Concentrations in Raw Water

Particles

The 204 raw water particle counts (7 to 12 µm) produced a mean of 12,780/mL, maximum 979,820/mL, and minimum 730/mL.

The distribution of the observed values are summarized in Figure 8. This figure indicates that more than half the time the particles in the 7 to 12 µm range were 5500/mL or less. This distribution range also shows that 80% of the time the particle counts ranged from 2500/mL to 15000/mL. Particle counts tended to vary extensively and erratically.

Temperature

The temperature of the water was observed daily to serve as a basis for evaluating other parameters but also to evaluate if temperature had any apparent effect on performance. The raw water temperature tended to fluctuate erratically from hour to hour particularly in the summer and thus the water temperature has been reported for the slow sand filter effluent as this value tended to be more consistent and were indicative of the true water temperature trends. A true warming or cooling trend would change the effluent temperature in 12 to 24 hr. The water temperature readings (summarized in Tables 25 and 26), represent 733 observations; the daily values are reported in Figure 14, pages 81 through 89. The average temperature was 9.7°C with a maximum of 25°C and a minimum of 0°C.

TABLE 25. WATER TEMPERATURE DATA

Temperature (°C)	Average Percent of Values	
	Less than	Equal to or Greater
2	38	62
6	48	52
11	56	44
16	69	31
21	92	8

TABLE 26. SEASONAL DISTRIBUTION OF WATER TEMPERATURE

Temperature (°C) Equal or Above	Average Occurrence and Duration (5/82 - 5/84)	
21	July - August	29 days
16	June - September	111 days
11	May - October	162 days
6	April - October	192 days
2	April - December	255 days

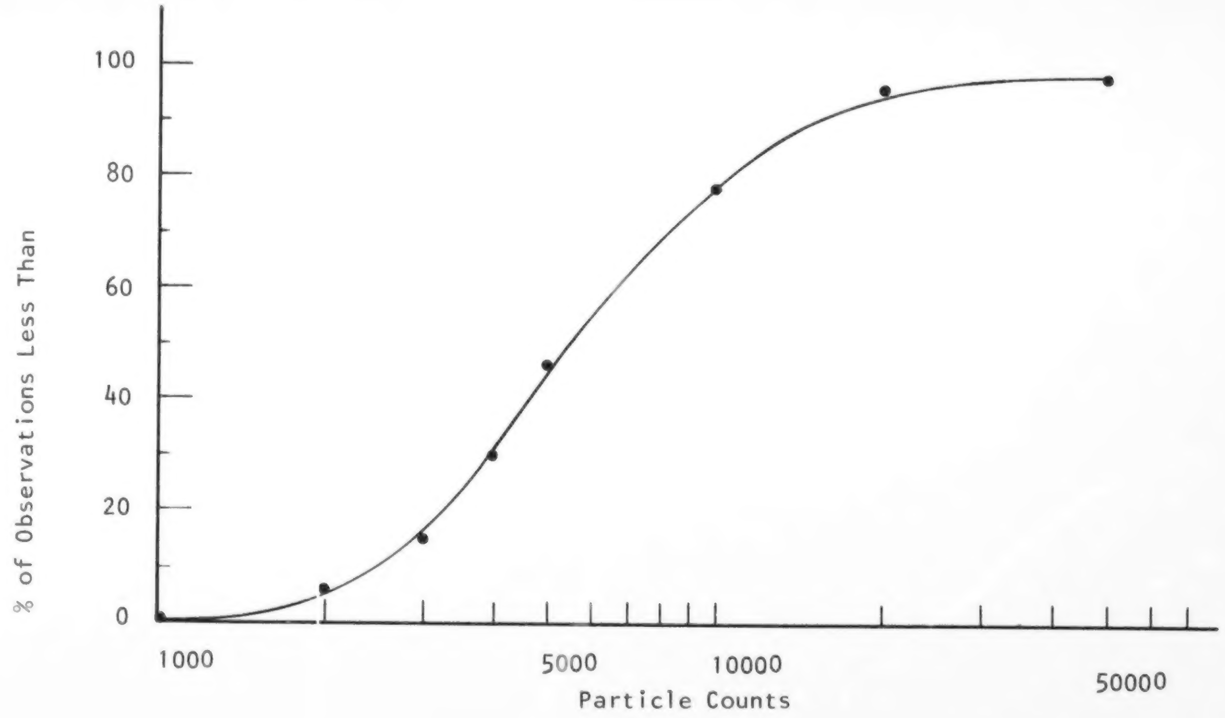


Fig. 8. Observed Occurrence of Particle Count in Raw Water No./1 mL

Table 25 indicates that the water tended to be very cold most of the time with some very warm water for about a month in the summer. About half the time the water was 5°C or below and about 40% of the time the water temperature was below 2°C. These cold temperature conditions are very favorable to Giardia cyst survival.

Table 26 summarizes the seasonal distribution of water temperatures during the course of the study. The coldest water tended to occur during the winter and early spring months with maximum temperatures occurring about the first of August. This temperature distribution indicates that the variation was predominantly the result of solar influence. It would appear that subsurface and groundwater flow provided only minimal impact on the temperature characteristics.

SLOW SAND FILTER

Bacterial Removal - Normal Operation

Normal, natural, ambient operating conditions for the slow sand filter were evaluated from data collected during the operating time between special spiking and cleaning studies. The periods of ambient operation were June 18, 1982 - January 24, 1983; February 10 - February 27, 1983; March 29 - April 18, 1983; June 1 - June 30, 1983; August 4 - October 19, 1983; December 21, 1983 - May 4, 1984. During these periods of time only natural occurrences affected the water quality. The reductions in bacterial concentrations are summarized in Table 27 for all the observations made during the periods mentioned. All values are for unchlorinated effluent.

TABLE 27. BACTERIAL REMOVAL AS PERCENT REDUCTION - AMBIENT OPERATION ALL PERIODS - 6/18/82 - 5/4/84

Parameter	Number of Samples	Mean	Maximum	Minimum
Total Coliform	67	79%	99.99%	-600%
Standard Plate Count	67	89%	99.99%	-200%

This table shows that the average coliform reduction was about 80% and the average standard plate count reduction was about 90%. However, there were times when there were negative reductions which might indicate poor treatment or could be the result of very high quality water reaching the inlet after poor quality had been applied. Raw water quality had extreme variations from sample to sample with very high values at times and extremely low values for the next sample. The slow sand filter did not show a response to sudden improvement in quality and thus negative reductions would tend to appear because of extremely high raw water quality. Sudden rains or other disturbances produced short duration spikes of bacteria and materials which at those times produced high loads but usually high percent reduction.

Figures 9 and 10 show the bacterial concentration distribution for all samples tested under ambient conditions and provide a better indicator of the water quality. These comparisons show the percent of the samples with bacterial concentrations equal to or less than a given value for the influent and effluent streams.

These figures indicate that there was an overall improvement in water quality by slow sand filter treatment under ambient operation of 96% for total coliform and 96% for standard plate count. These values are higher than the mean values in Table 27 because the few negative and low reduction values heavily influence the mean value. These figures show that for all the samples 90% of the standard plate count determinations contained 8/mL or less in the effluent and 430/mL in the influent. For coliform 90% of the coliform determinations contained 14/100 mL or less in the effluent and 1200/mL in the influent. At the median value the overall improvement in bacterial quality was 98% for standard plate count and 99% for coliform.

Figure 11 compares the percent of samples collected during normal operation with the percent reduction obtained for total coliform and standard plate count. The response in each case was very similar for both types of bacterial testing. For total coliform 80% of the samples showed a bacterial reduction of 88% or better and from Figure 9, 80% of the effluent samples had less than 7 total coliform per 100 mL and 90% had less than 13 total coliform per 100 mL (59% contained 1/100 mL or less) with a maximum of 100/100 mL. In the case of the standard plate count analysis, 80% of the samples indicated 88% reduction or better and 90% of the samples showed 80% reduction or better and from Figure 10, 80% of the effluent samples had less than 4/mL and 90% less than 7/mL (25% of the samples contained 1/mL or less) with a maximum of 150/mL.

The bacterial concentrations in the effluent are all for undisinfected water. The effluent bacterial values reported for all ambient conditions are such that normal disinfection could be expected to readily reduce the values to zero.

Recovery From Cleaning

The slow sand filter was cleaned a total of five times during the study, 5/10/82, 1/24/83, 7/5/83, 10/20/83, and at the end of the study. Two of these times the filter was studied for natural recovery under ambient conditions (1/24/83, 10/20/83); one time for recovery with sewage spiking (7/5/83); and one time (5/10/82) with limited recovery evaluation. The last time cleaning was performed was after all data collection had been terminated.

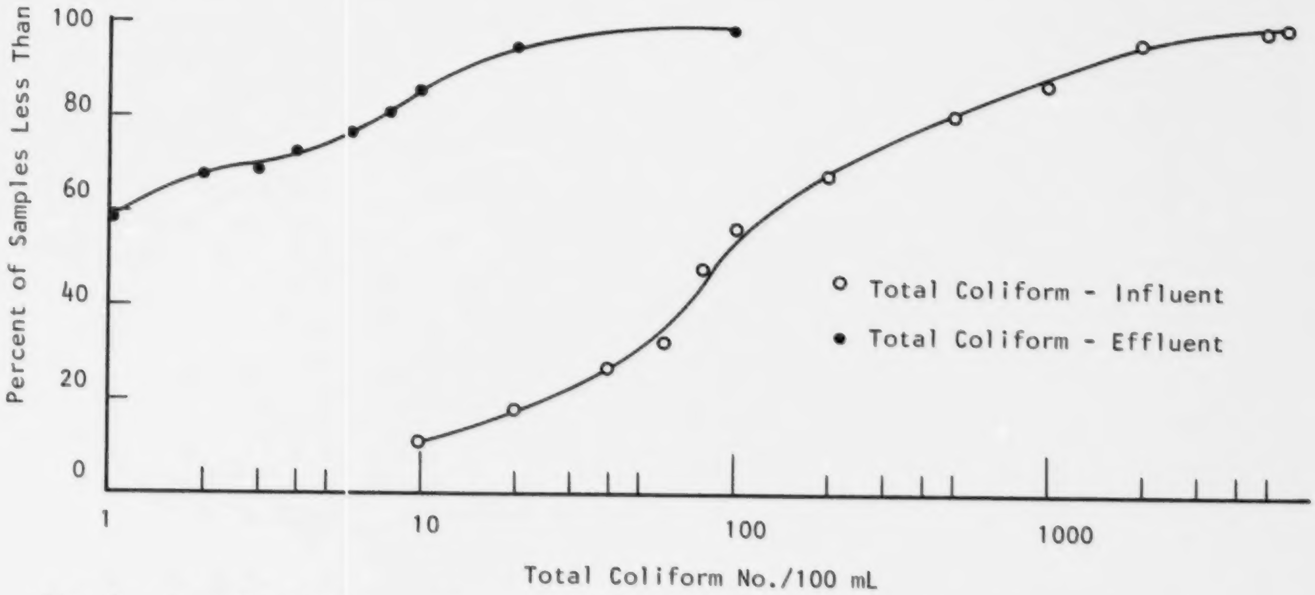


Fig. 9. Slow Sand Filter - Observed Occurrence of Total Coliform in Influent and Effluent, Normal Operation - Filtration Rate 0.08 m/hr

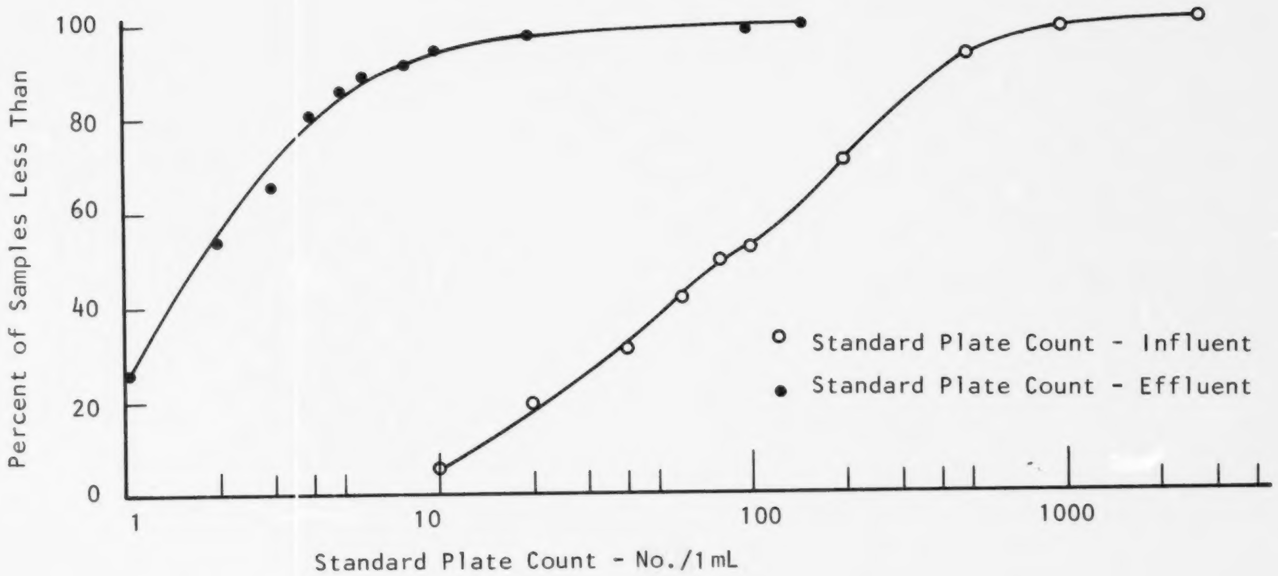


Fig. 10. Slow Sand Filter - Observed Occurrence of Standard Plate Count in Influent and Effluent, Normal Operation - Filtration Rate 0.08 m/hr

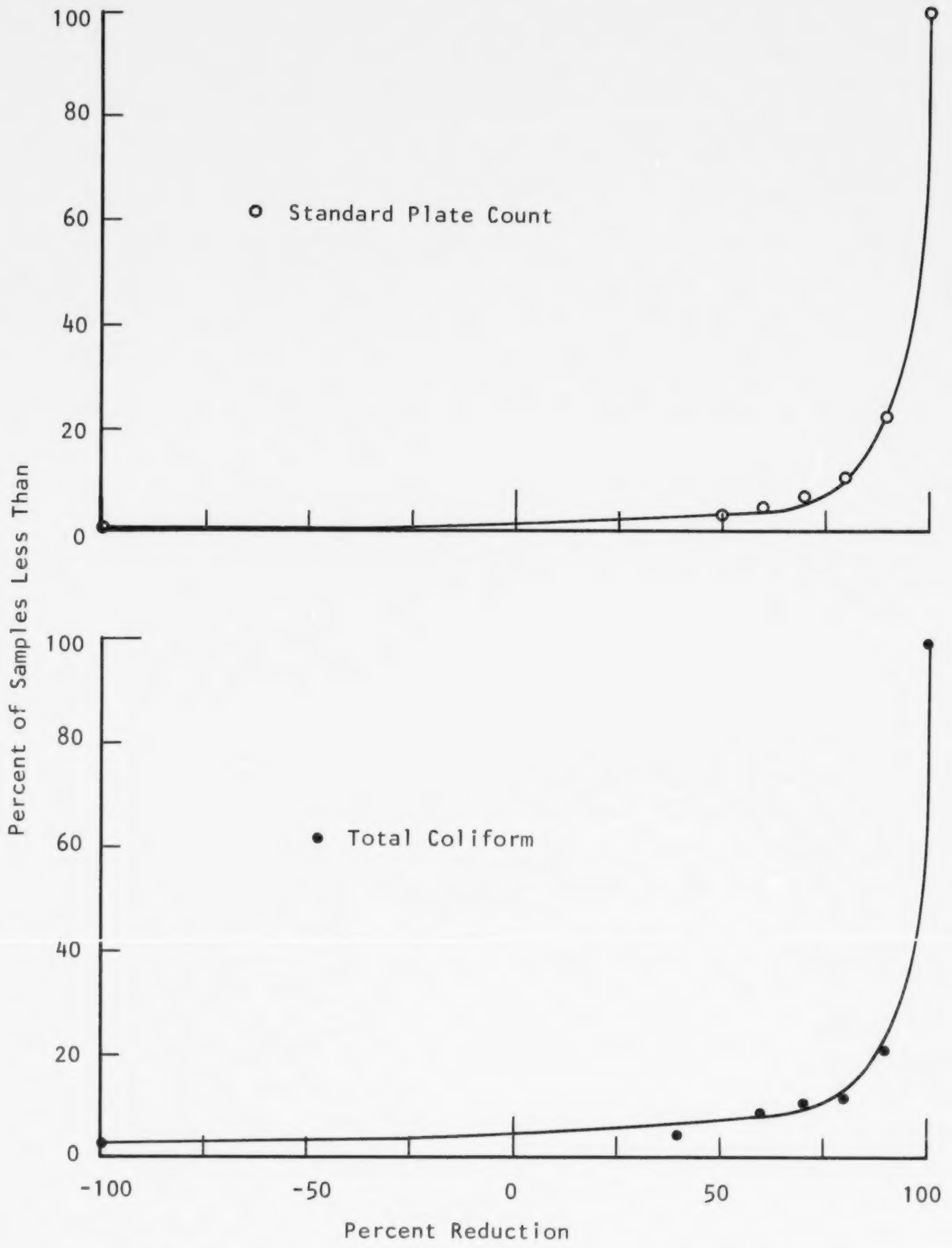


Fig. 11. Observed Occurrence of Percent Reduction of Total Coliform in Slow Sand Filter - Normal Operation Filtration Rate 0.08 m/hr

The parameters considered in evaluating the recovery were turbidity, total coliform, standard plate count, and particles in the 7 to 12 μm range. All of these parameters were affected by cleaning. Usually some degredation in percent removal was observed after cleaning. The response effects were variable from time to time and parameter to parameter. In general the precautions mentioned in the literature of not using the water from the slow sand filters for several days after cleaning to several weeks after initial start-up[18,21,30] was substantiated. Colder temperatures[18,21,30] require longer periods of recovery or ripening than do warmer temperatures. The results from this work confirm this general concept in that there were times when good reductions were observed in shorter periods of time, particularly during warm water conditions.

The cleaning recovery in May 1982 involved a recovery study after the filter had not been in operation very long after not having been used for for about 4 years. An attempt was made to also spike the influent with sewage at this time to ensure that there would be enough bacteria present, but the system for spiking did not work well and in effect the results were for natural conditions.

Figure 12 and 13 show the effect on total coliform and standard plate count removal during recovery from cleaning (5/10/82 - 6/10/82). Immediately after cleaning the total coliform reduction showed degradation to 53% after 8 days and recovered to 99% removal in 15 days. However, at other times Figures 12 and 13 show that the after cleaning reductions were observed to be even lower than the observed 30-day recovered value. The total coliform count in the effluent decreased (Figure 12) steadily during the recovery period from 140/100 mL to 10/100 mL and remained at or about the 10/100 mL value or less for several weeks and months.

The standard plate count (Figure 12) was not so pronounced in its response. The values showed degradation to 92% reduction in 8 days and recovery to 99% reduction in 23 days but the percent reduction tended to be similar long after cleaning. The standard plate count in the effluent decreased steadily during the recovery period from about 12/mL to one or less per mL. Subsequent natural values tended to remain about 10/mL.

Turbidity appeared to to be affected by cleaning as percent reduction tended to deteriorate as shown in Figure 14, but the results were very erratic, fluctuating from about 50% removal to -210% removal in the first 4 days and from 96% to -33% removal in 23 days. There was an improving trend during that time in the maximum and minimum removal. During that period of time the effluent contained an average of 0.3 NTU with one 2.1 and one 1.6 NTU value.

The second cleaning occurred on January 24, 1983. The filter was somewhat more mature because it had been in operation for about nine months without cleaning. The head loss had been allowed to build up to about 150 cm to give data related to long run responses under natural conditions.

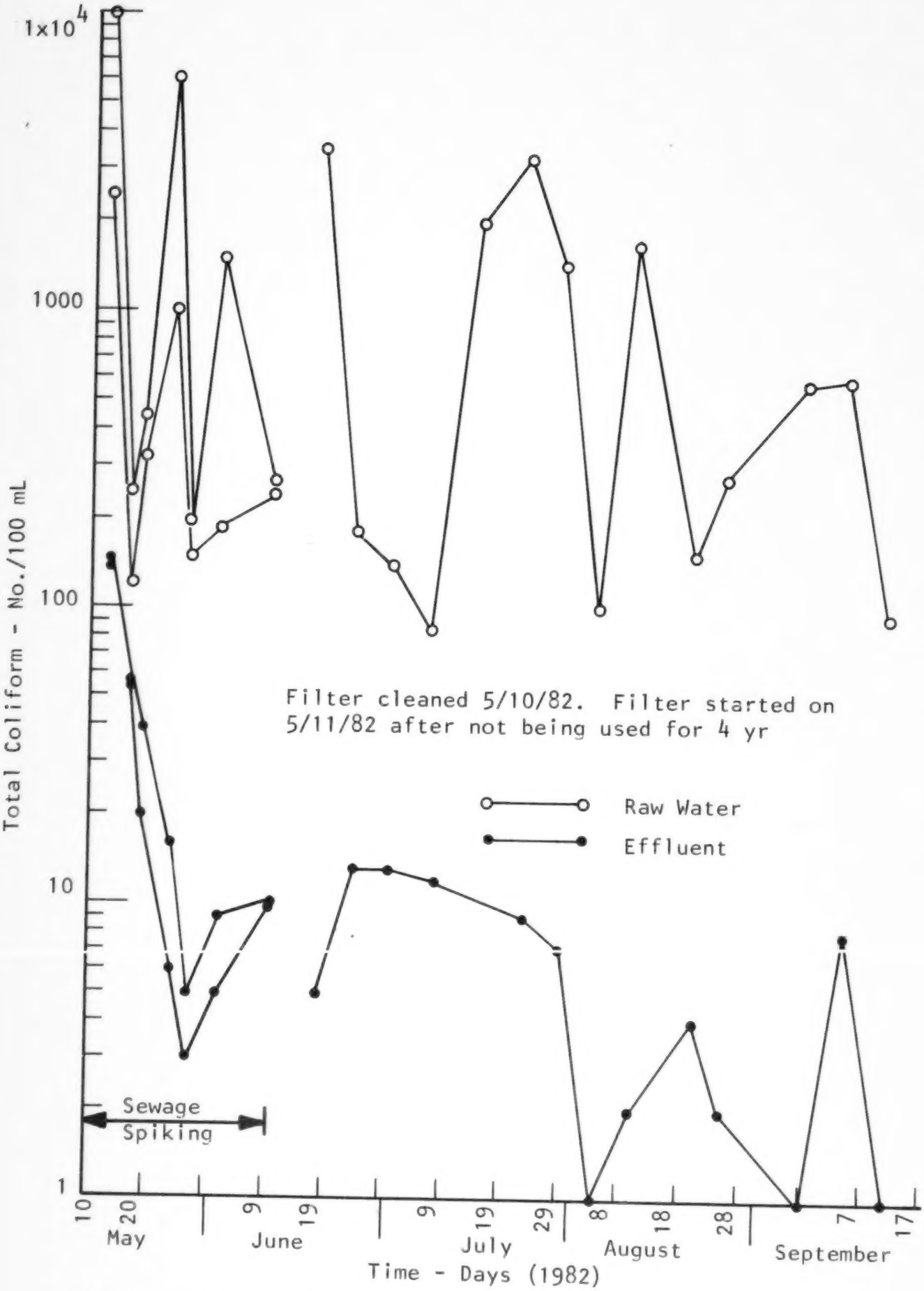
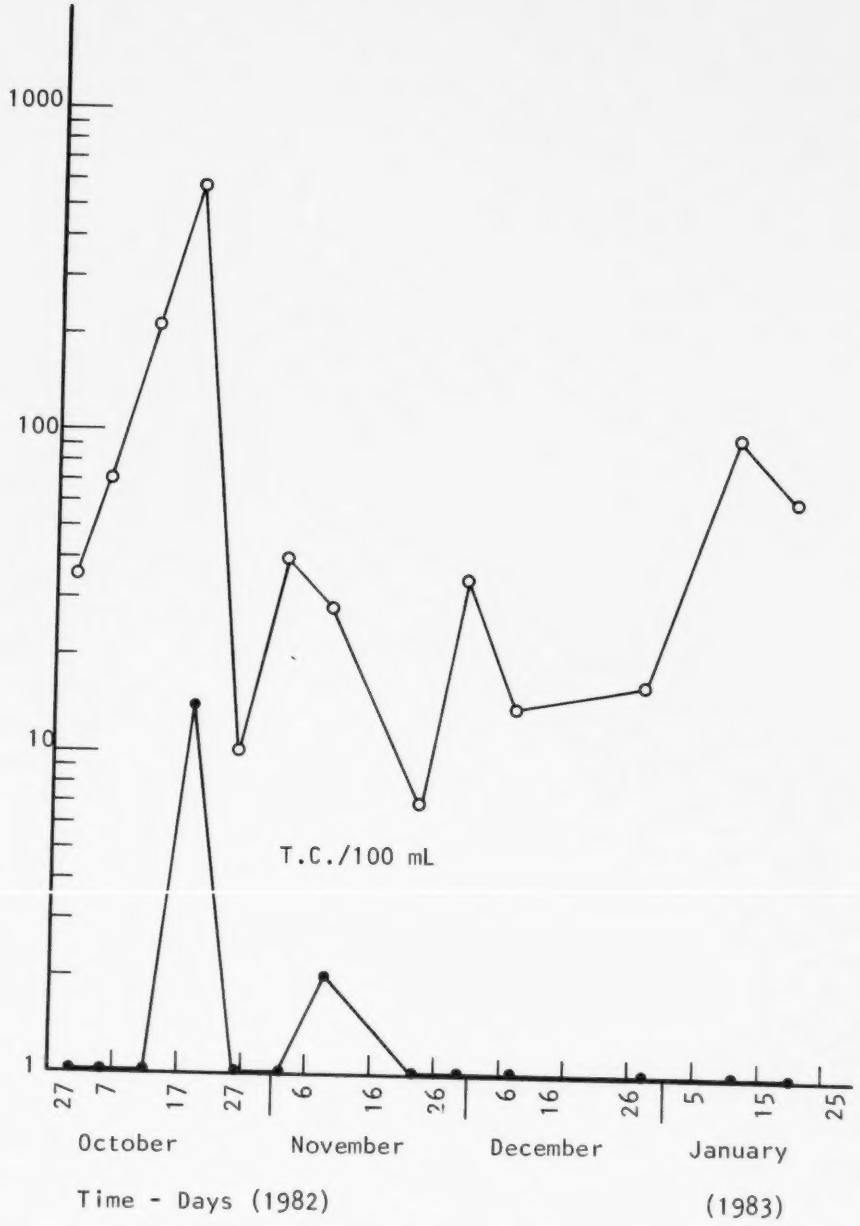
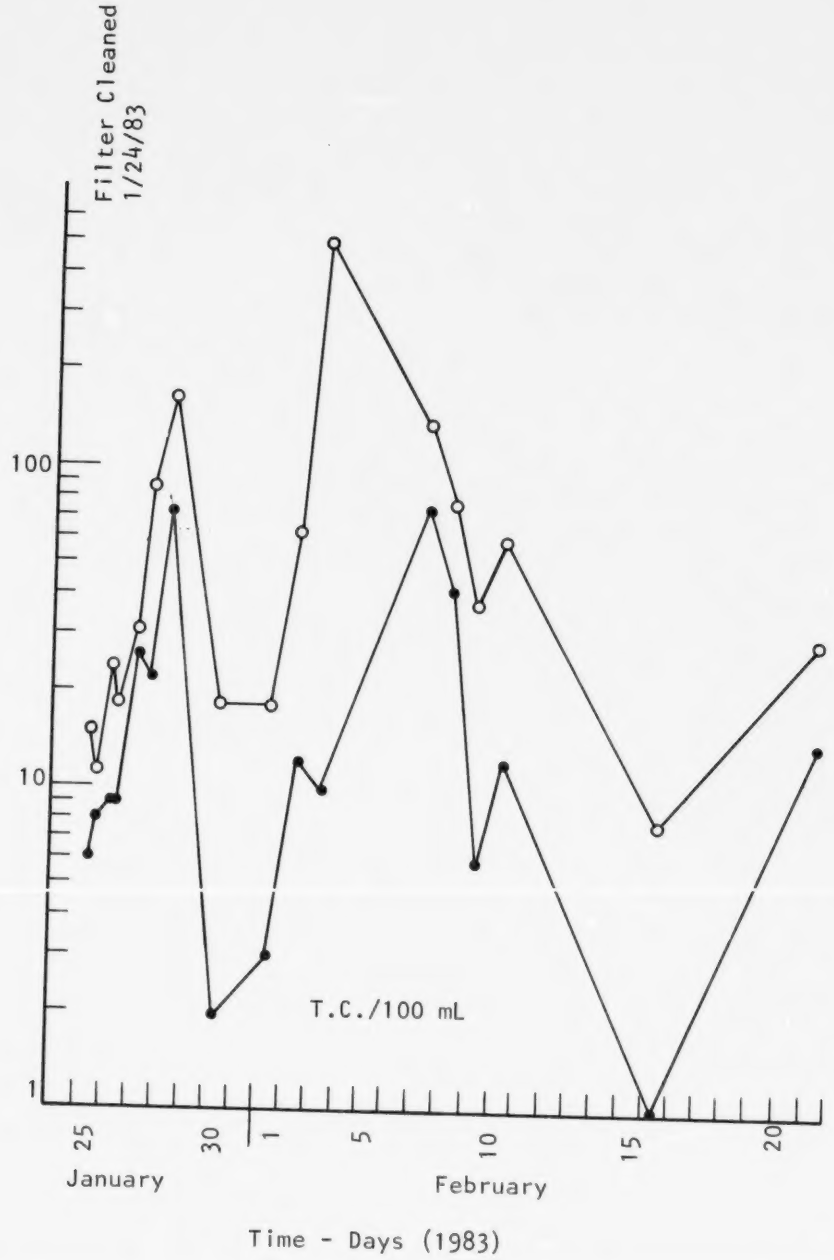
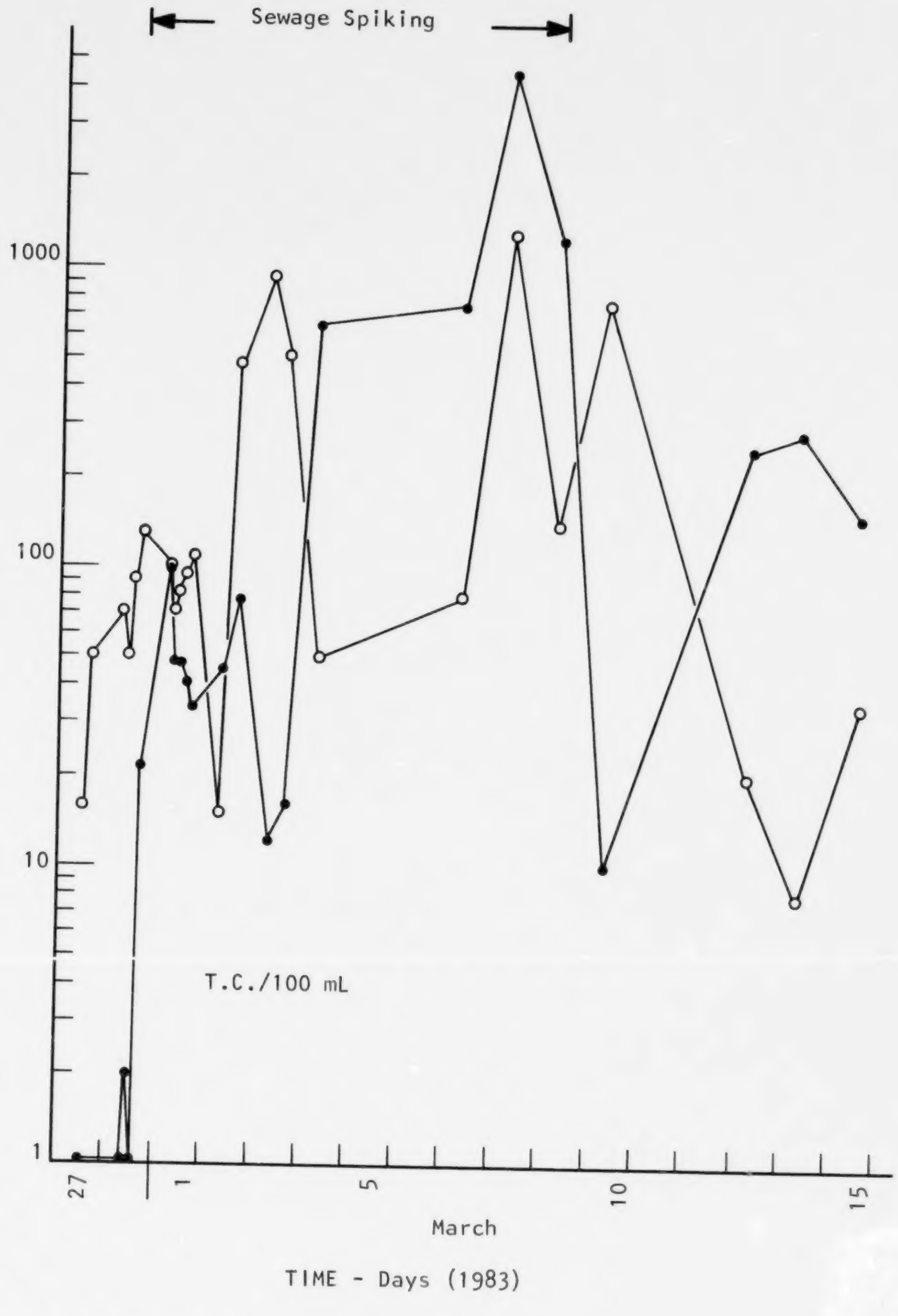
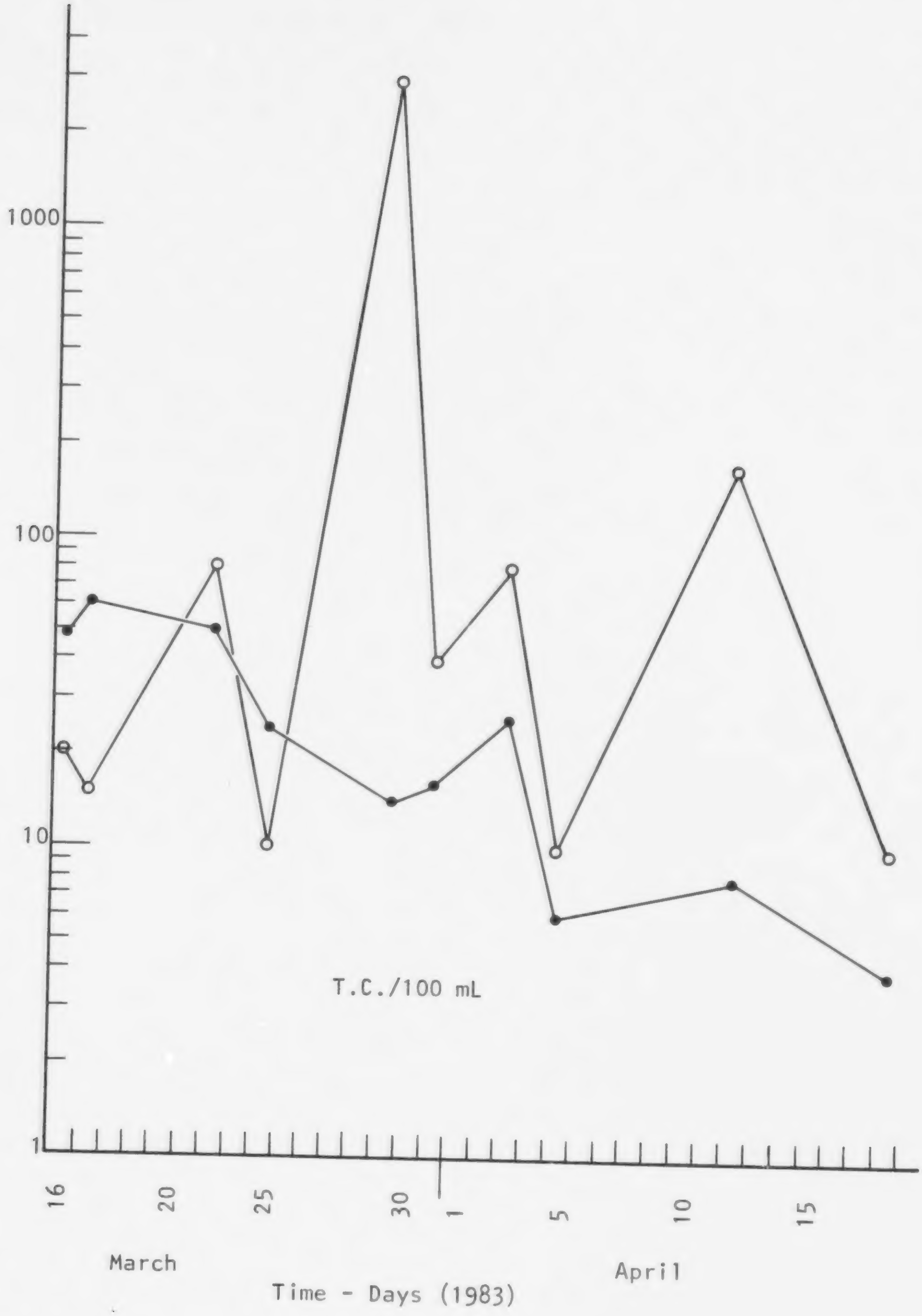


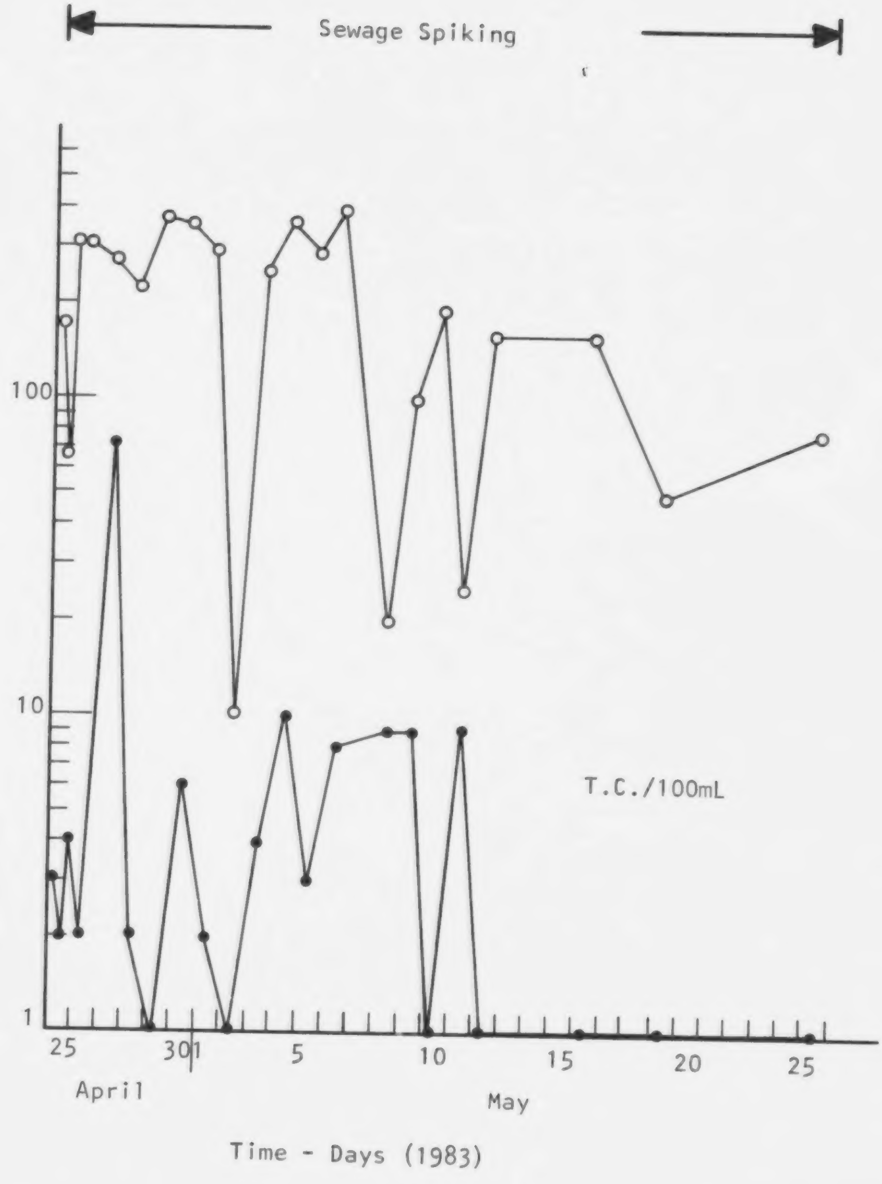
Fig. 12. Slow Sand Filter, Total Coliform vs Time - Filtration Rate 0.08 m/hr

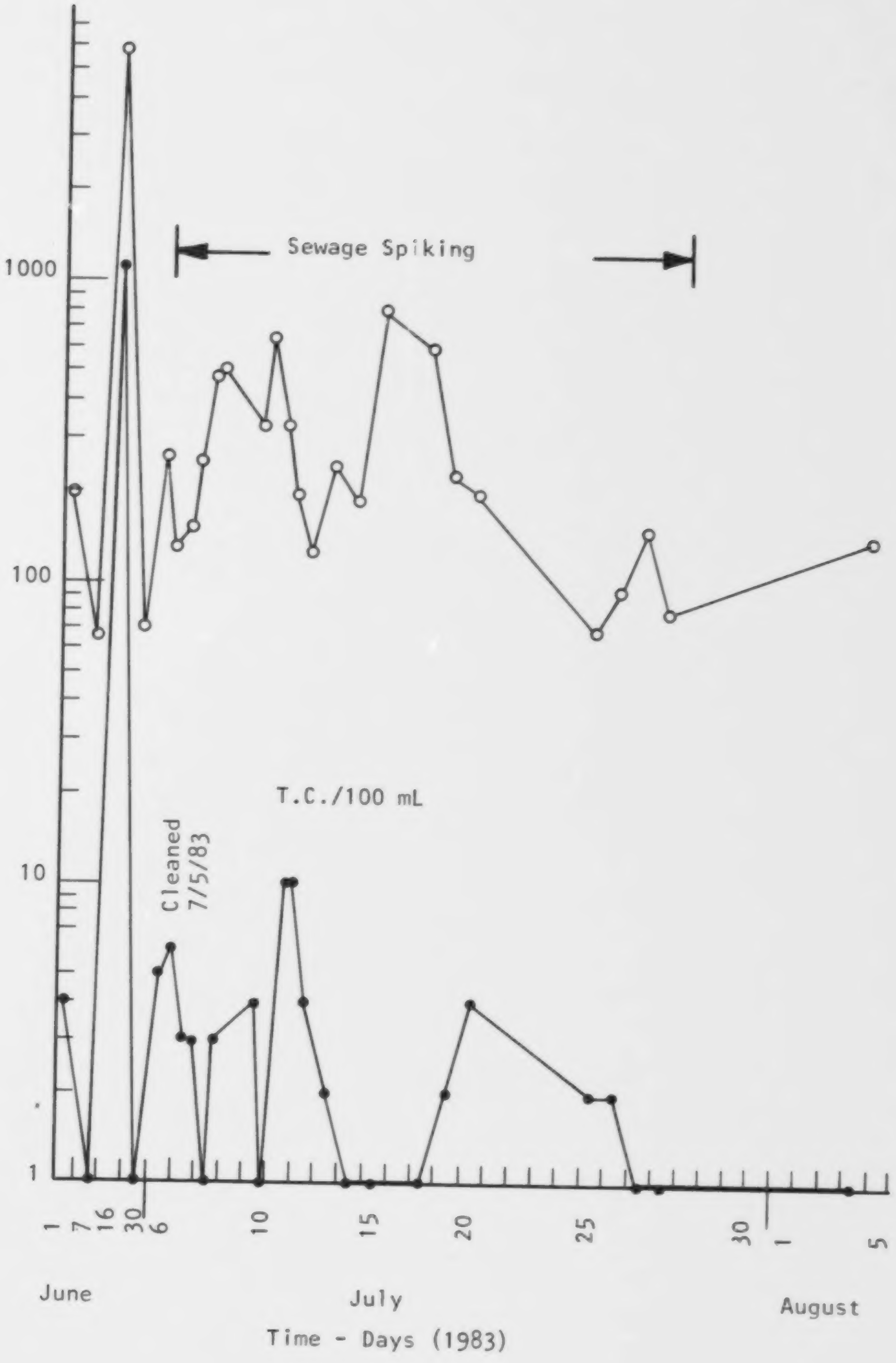

1000
100
10
1
T.C./100 mL
27
7
17
27
6
16
26
6
16
26
5
15
25
October
November
December
January
Time - Days (1982)
(1983)

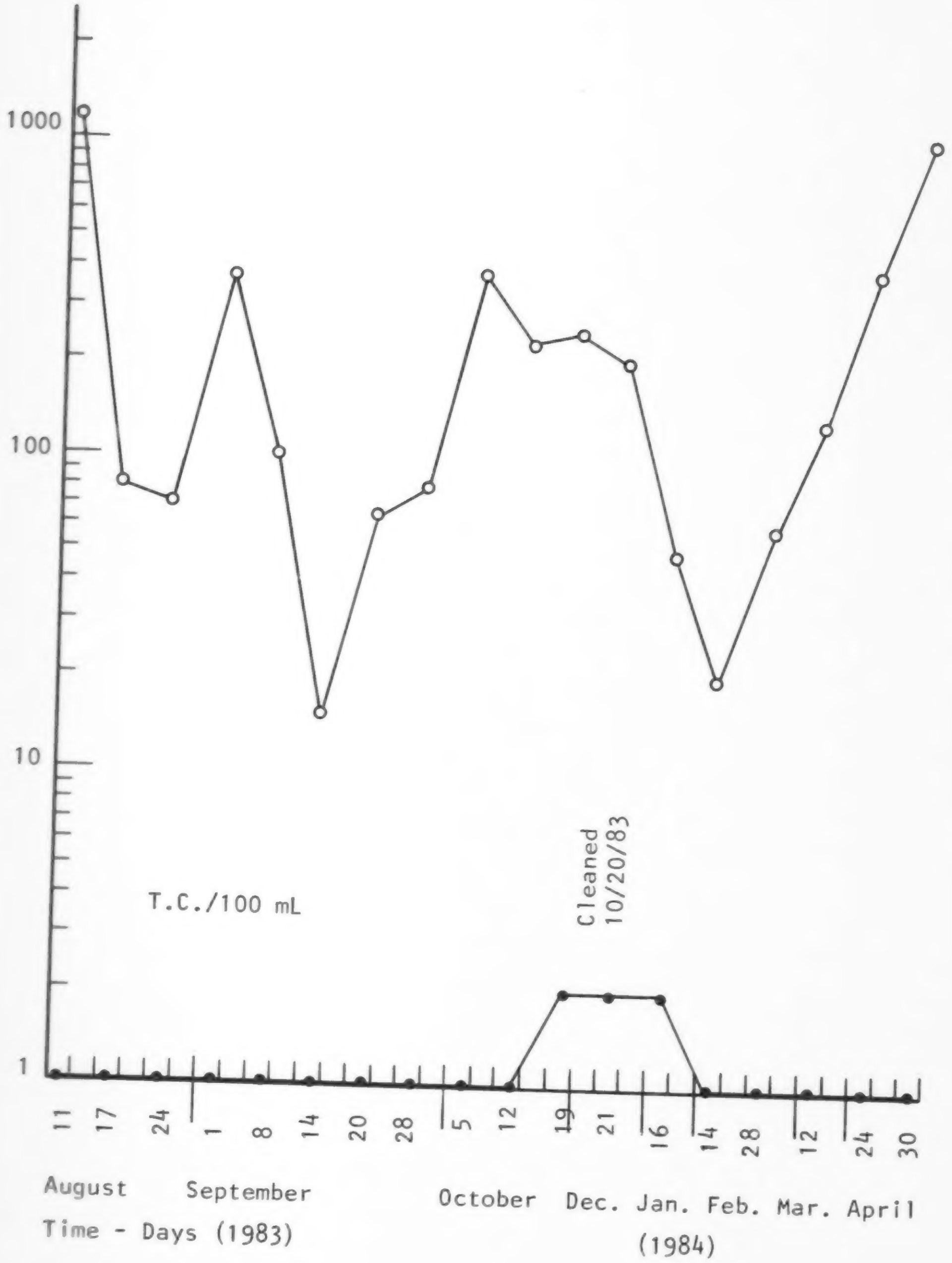

Filter Cleaned
1/24/83
100
10
1
T.C./100 mL
25
30
1
5
10
15
20
January
February
Time - Days (1983)

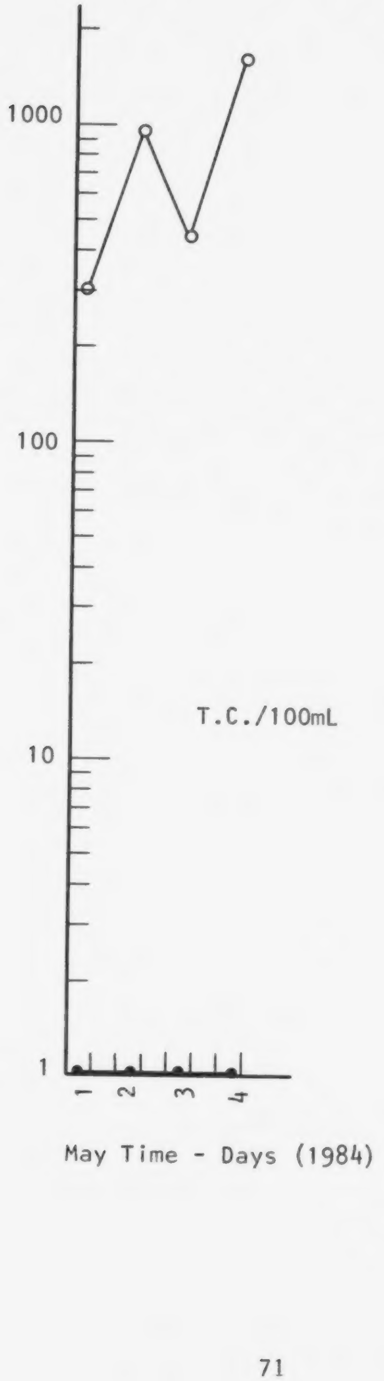

Sewage Spiking
1000
100
10
1
T.C./100 mL
27
1
5
10
15
March
TIME - Days (1983)


1000
100
10
1
T.C./100 mL
16
20
25
30
1
5
10
15
March
April
Time - Days (1983)


Sewage Spiking
100
10
1
T.C./100mL
25
30
1
5
10
15
20
25
April
May
Time - Days (1983)


1000
100
10
1
Sewage Spiking
T.C./100 mL
Cleaned 7/5/83
1
7
16
30
6
10
15
20
25
30
1
5
June
July
August
Time - Days (1983)


1000
100
10
1
T.C./100 mL
Cleaned 10/20/83
11
17
24
1
8
14
20
28
5
12
19
21
16
14
28
12
24
30
August
September
October
Dec.
Jan.
Feb.
Mar.
April
Time - Days (1983)
(1984)



May Time - Days (1984)

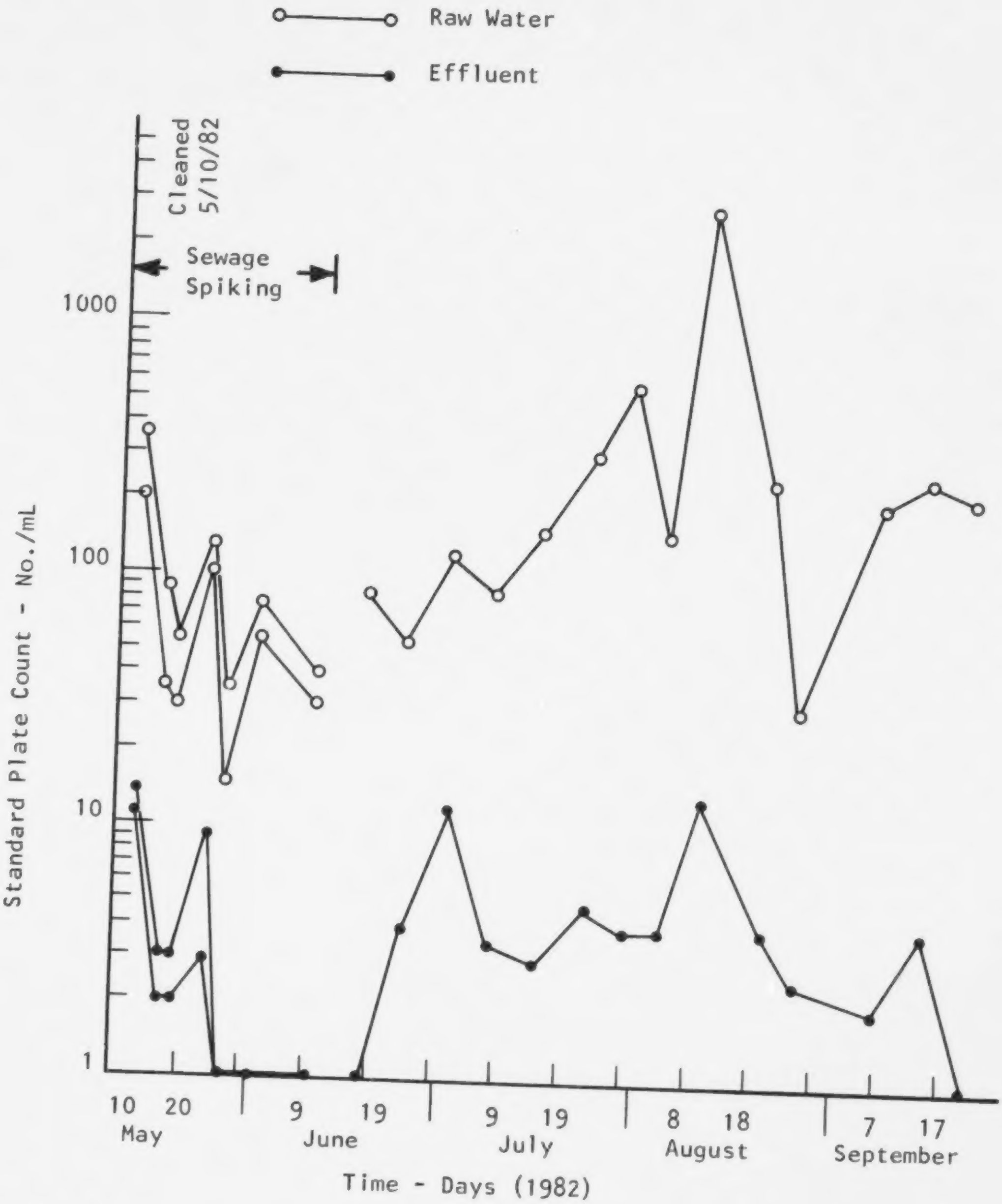
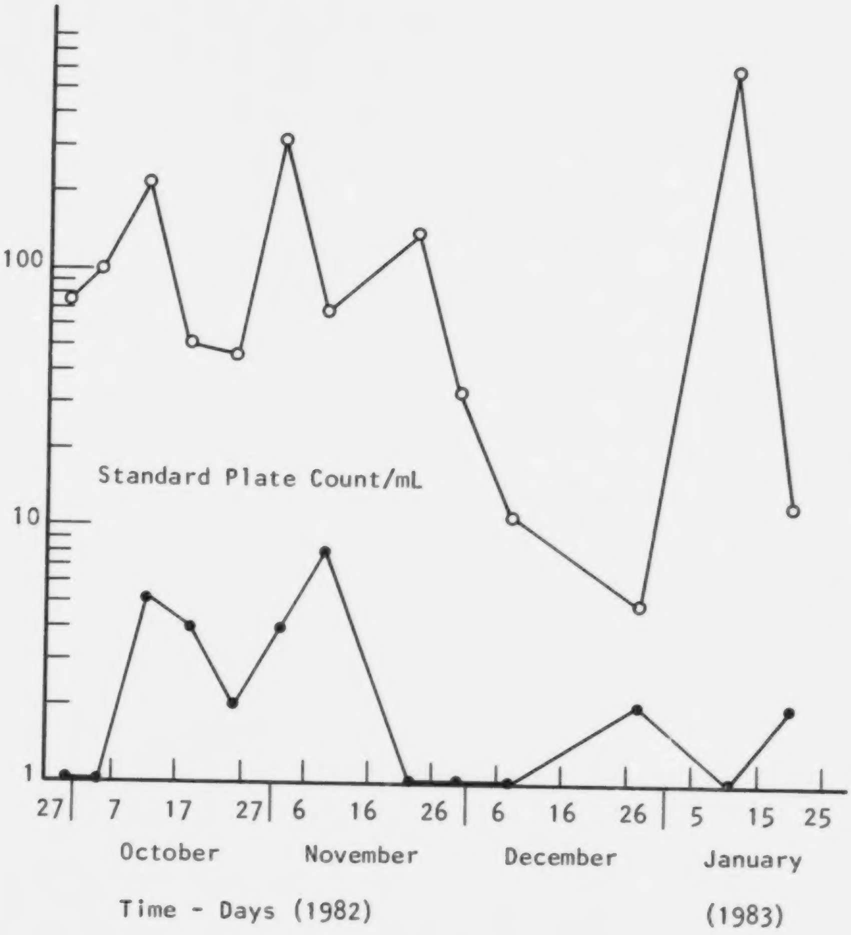
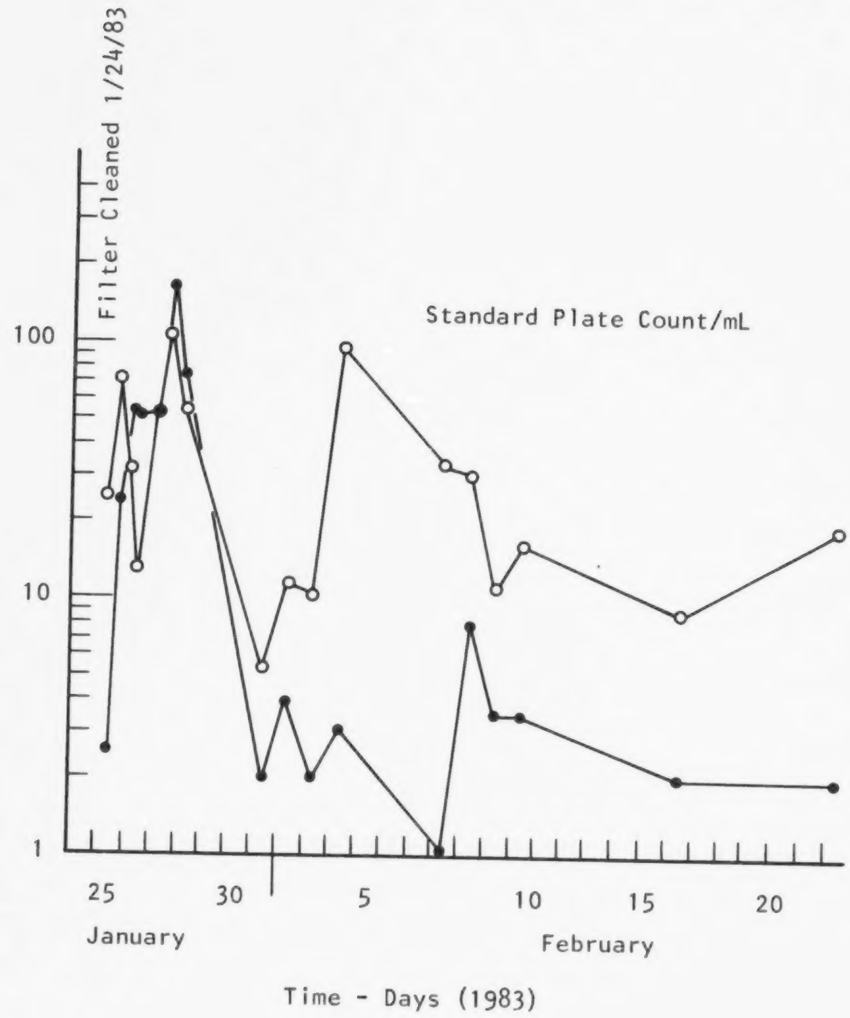
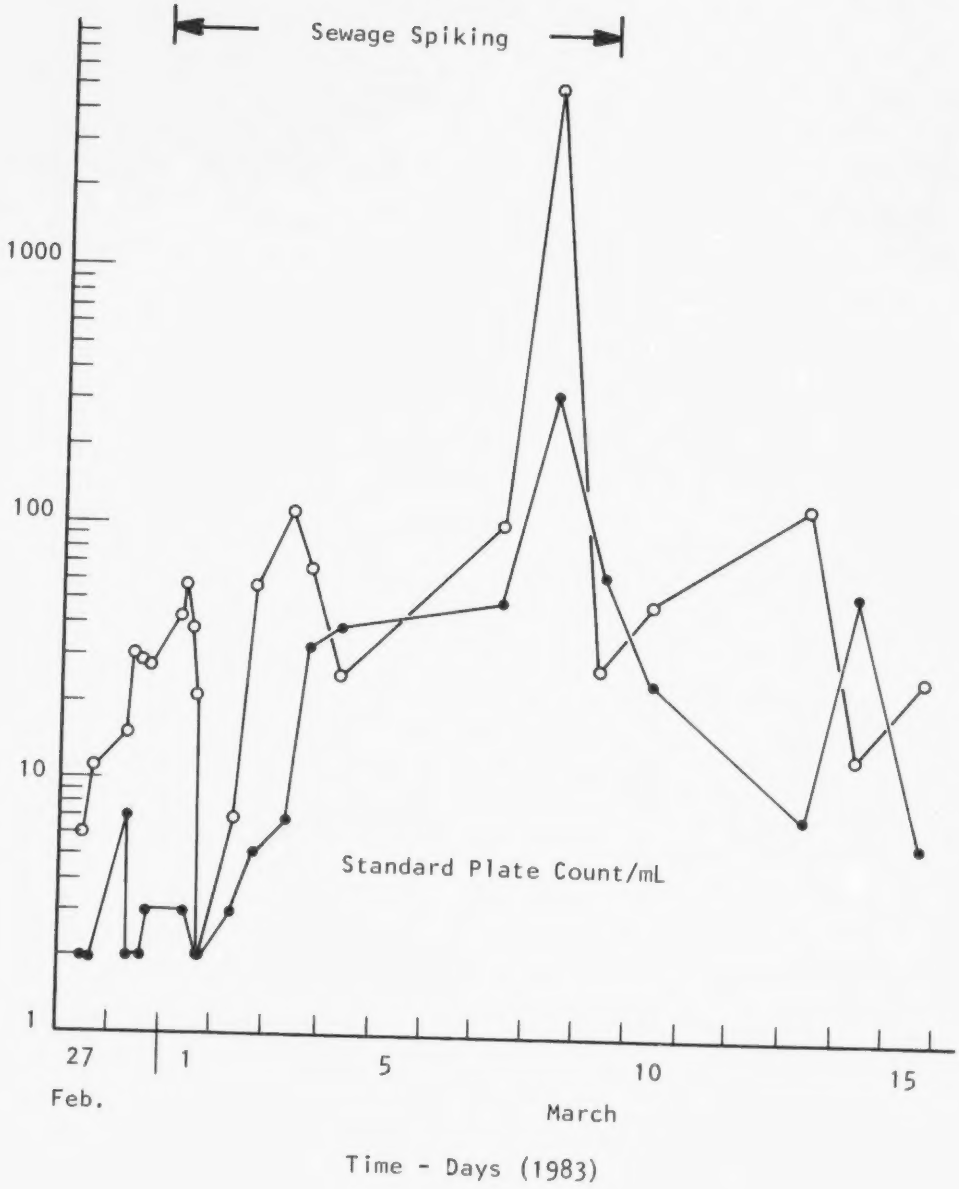
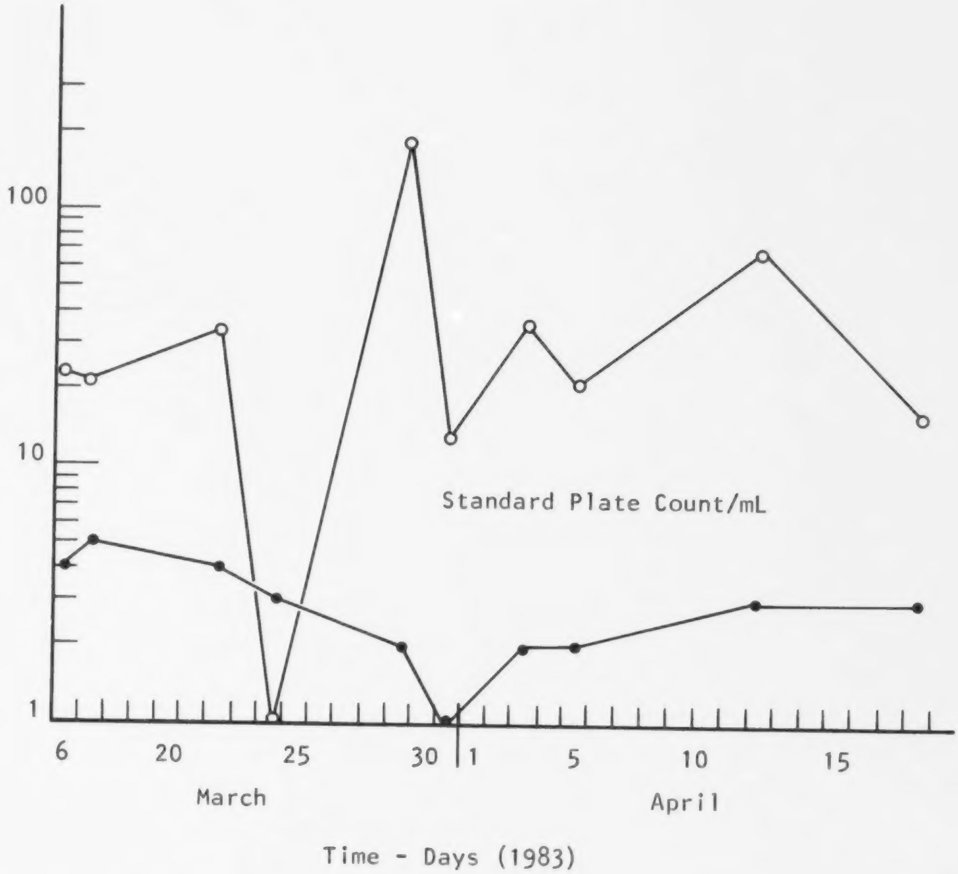


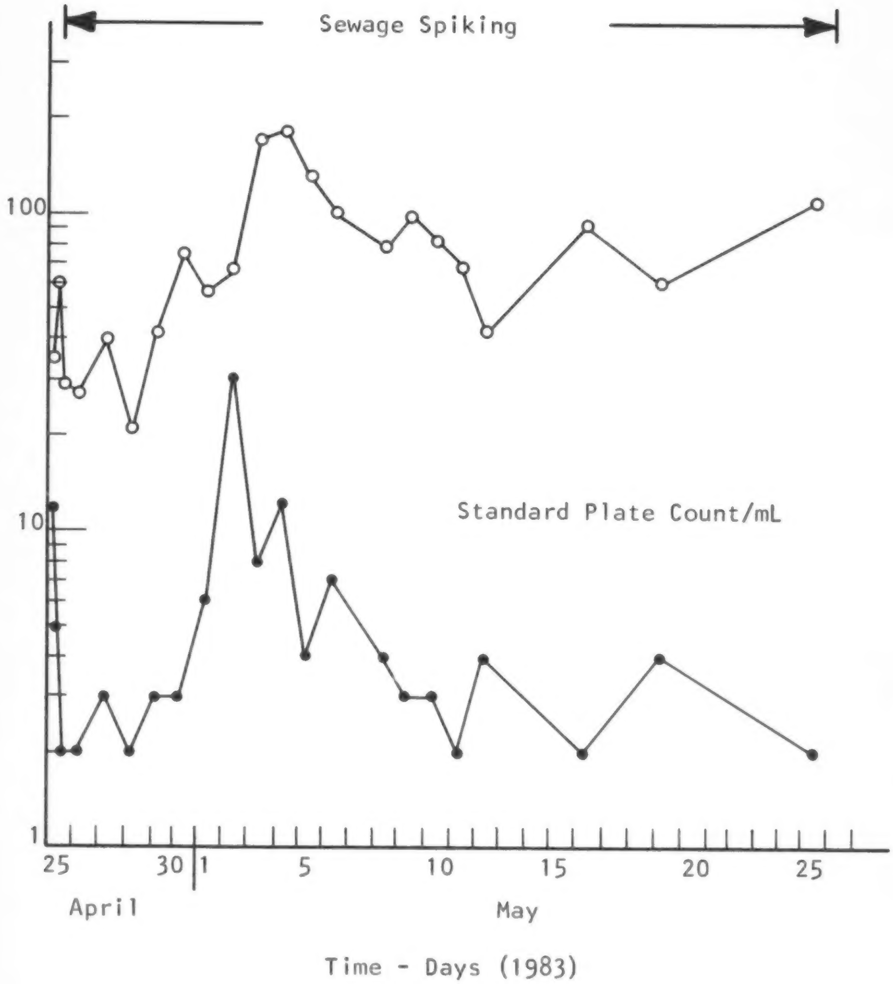
Fig. 13. Slow Sand Filter, Standard Plate Count VS Time - Filtration Rate 0.08 m/hr. (Filter Started on 5/11/82 After Not Being Used for 4 yr.)


100
10
1
Standard Plate Count/mL
27
7
17
27
6
16
26
6
16
26
5
15
25
October
November
December
January
Time - Days (1982)
(1983)

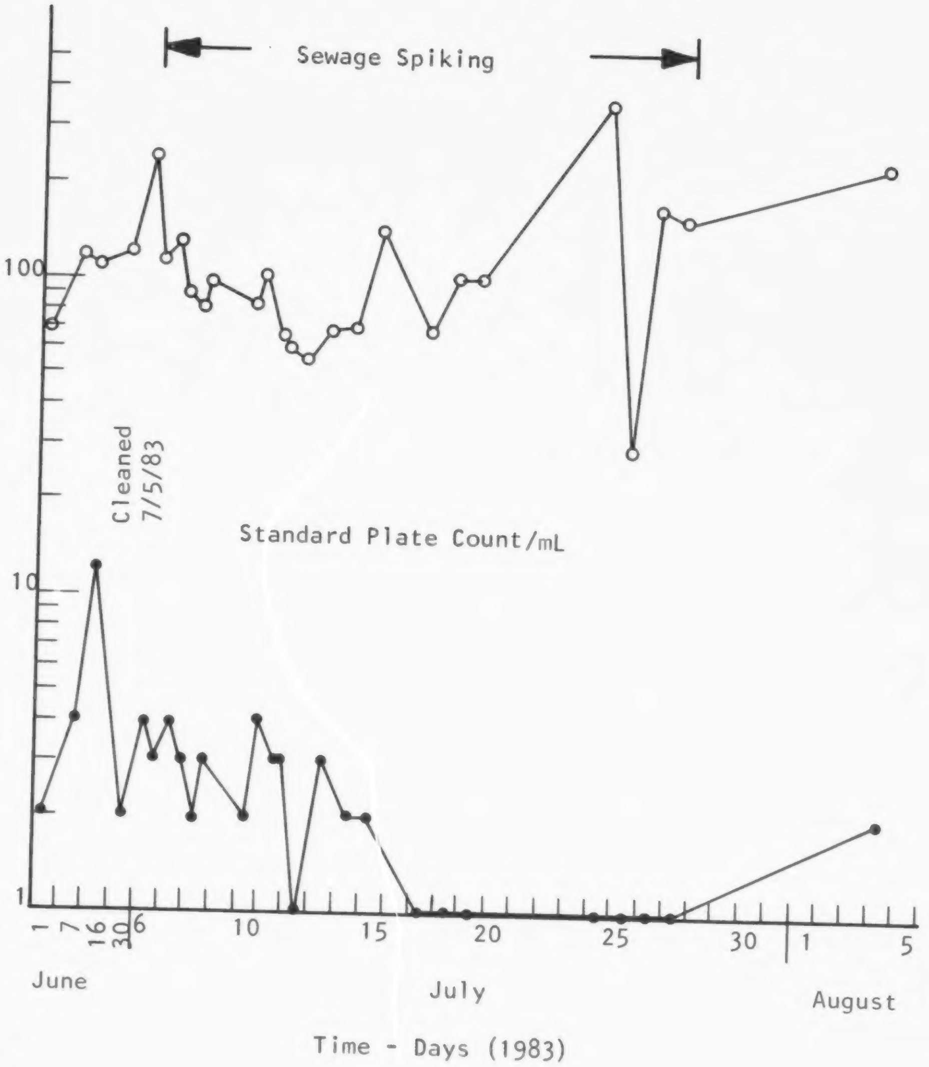
Filter Cleaned 1/24/83
Standard Plate Count/mL
100
10
1
25
30
5
10
15
20
January
February
Time - Days (1983)


Sewage Spiking
1000
100
10
1
Standard Plate Count/mL
27
Feb.
1
5
10
15
March
Time - Days (1983)

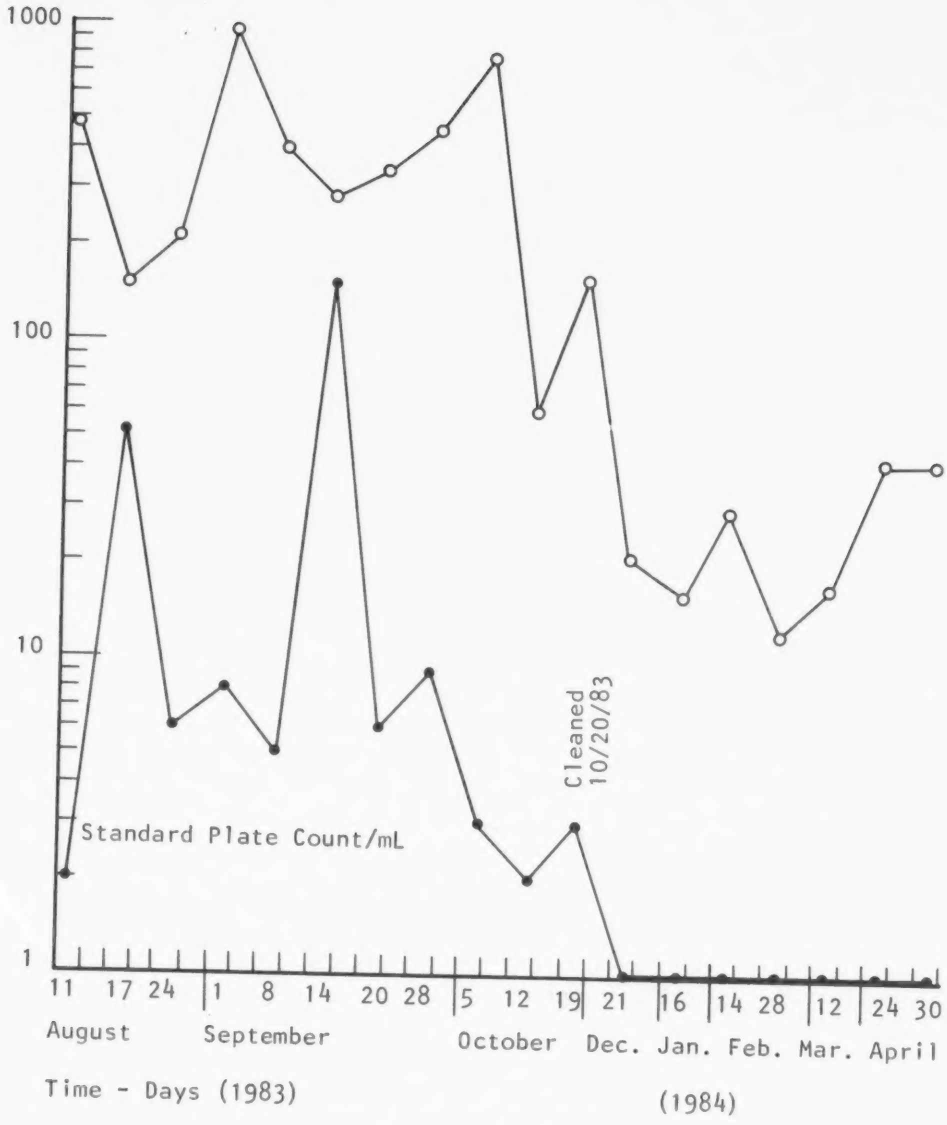

100
10
1
Standard Plate Count/mL
6
20
25
30
1
5
10
15
March
April
Time - Days (1983)

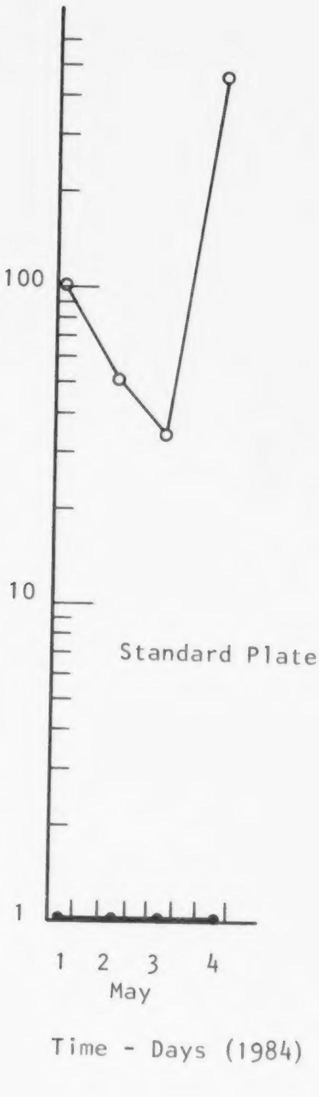


Sewage Spiking
100
10
1
Standard Plate Count/mL
25
30
1
5
10
15
20
25
April
May
Time - Days (1983)



Sewage Spiking
100
10
1
Cleaned 7/5/83
Standard Plate Count/mL
1
7
16
30
6
10
15
20
25
30
1
5
June
July
August
Time - Days (1983)


1000
100
10
1
Standard Plate Count/mL
Cleaned 10/20/83
11 17 24 1 8 14 20 28 5 12 19 21 16 14 28 12 24 30
August
September
October
Dec.
Jan.
Feb.
Mar.
April
Time - Days (1983)
(1984)



100
10
1
Standard Plate Count/mL
1
2
3
4
May
Time - Days (1984)

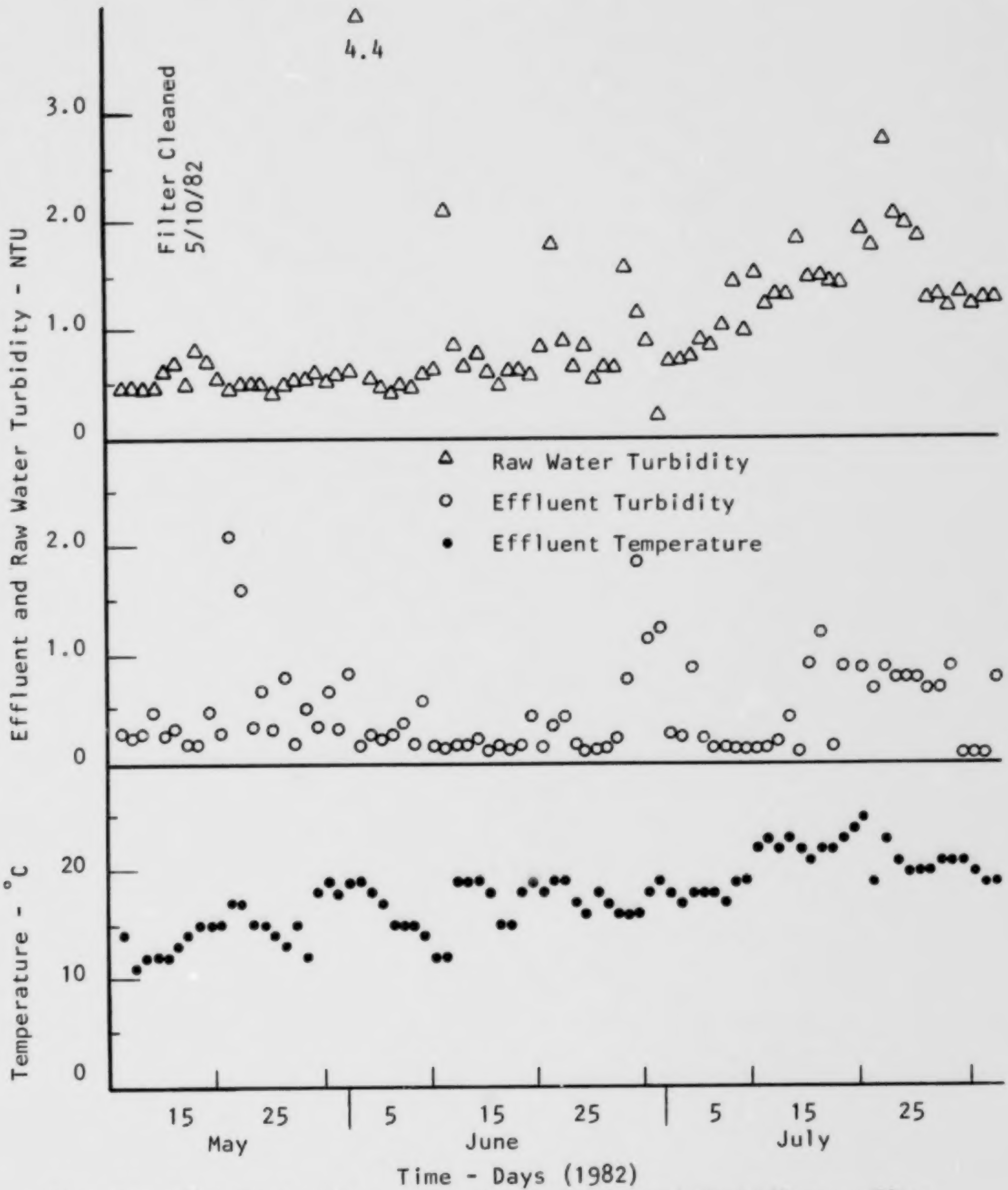
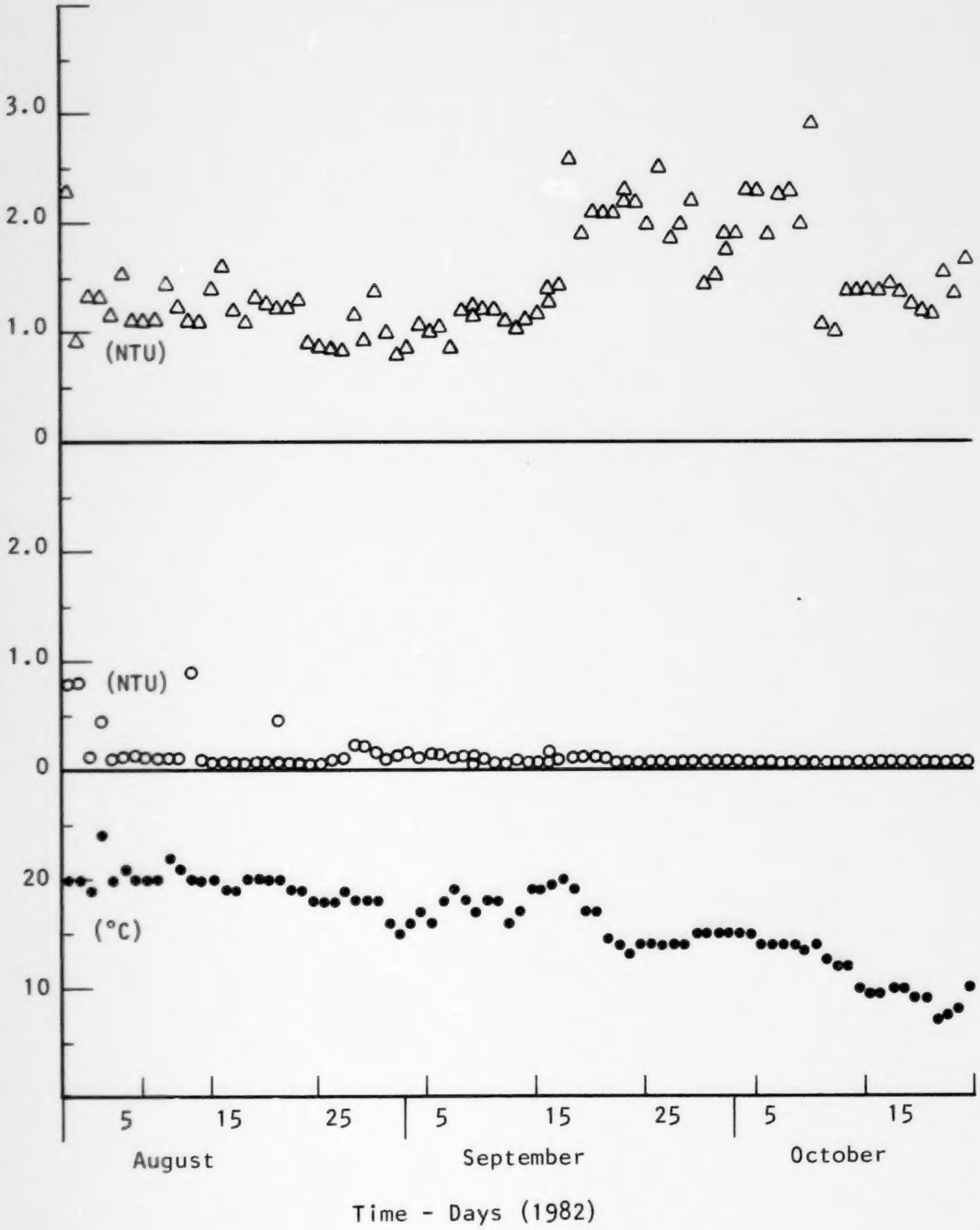
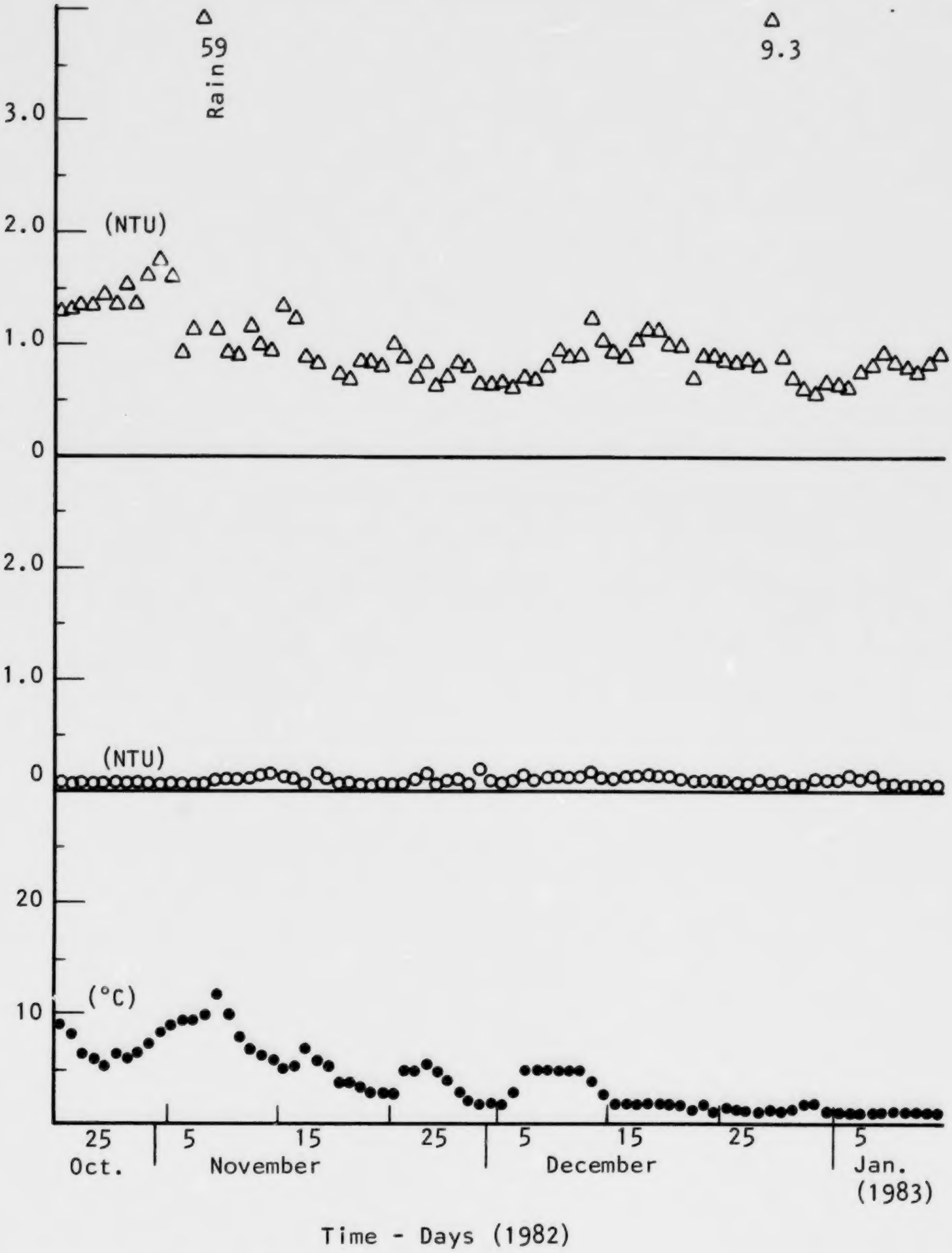
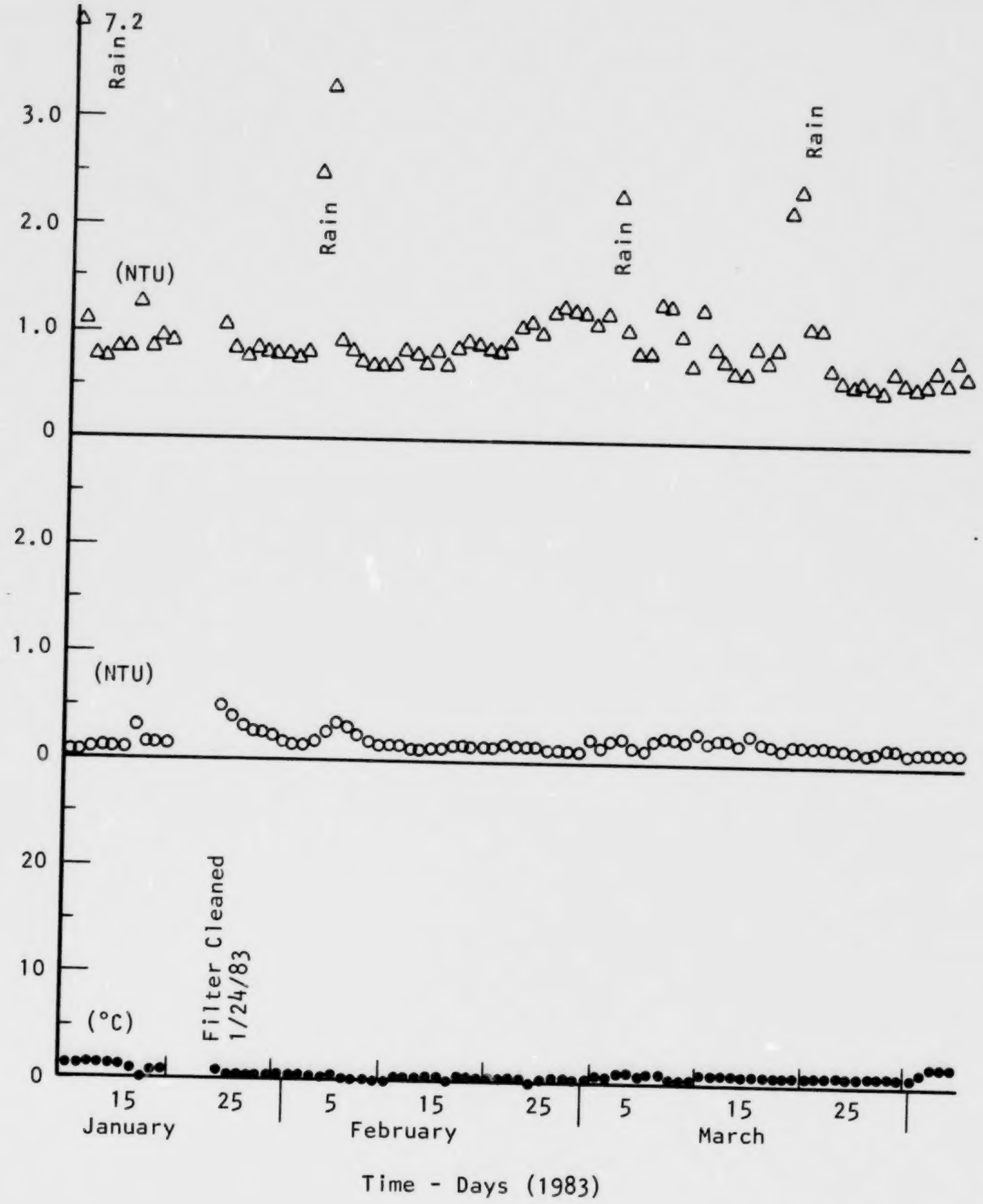


Fig. 14. Slow Sand Filter Water Temperature and Turbidity vs Time Filtration Rate 0.08 m/hr. (Filter Started on 5/11/82 After Not Being Used for 4 yr.)

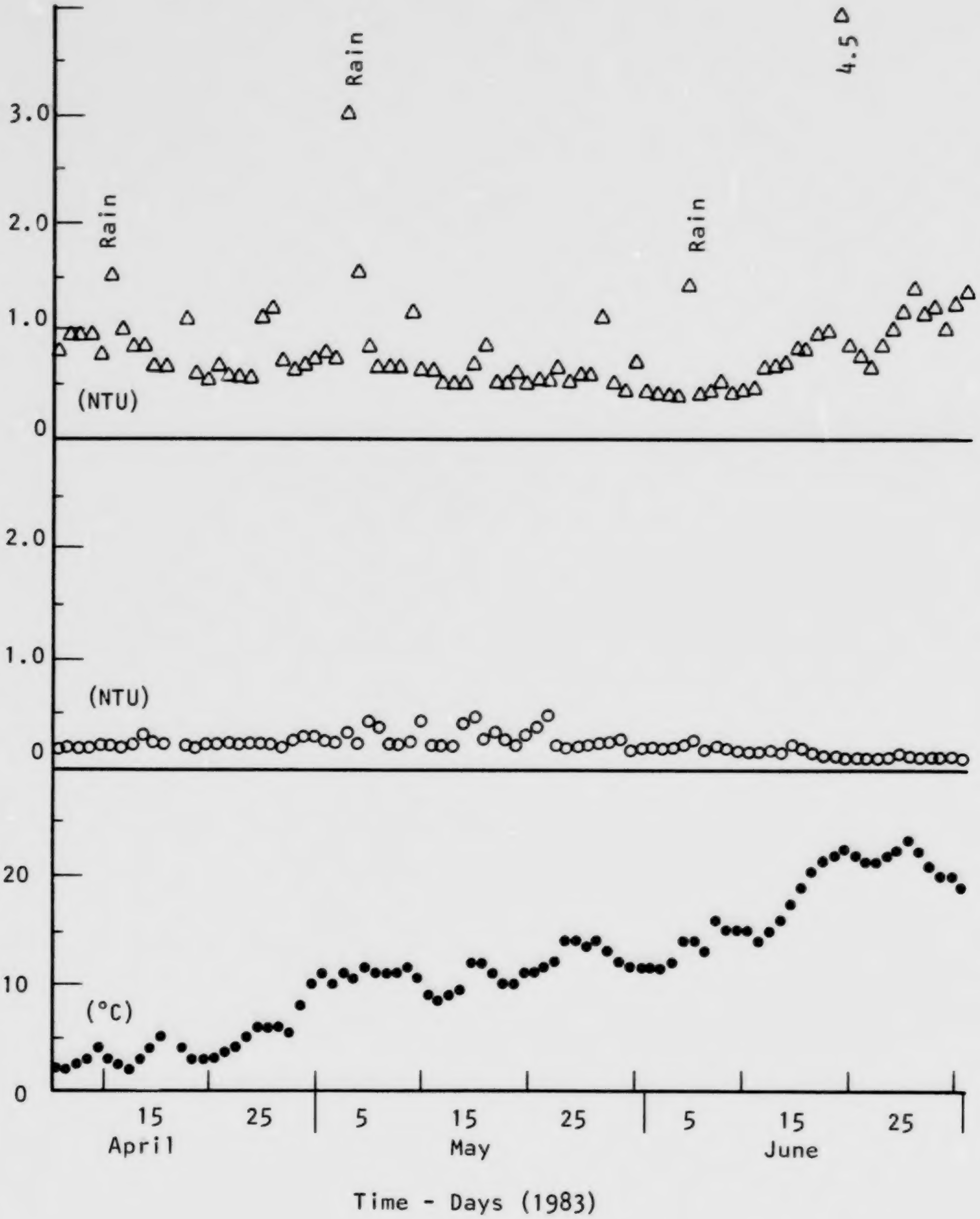

3.0
2.0
1.0
0
(NTU)
2.0
1.0
0
(NTU)
20
(°C)
10
5
15
25
5
15
25
5
15
August
September
October
Time - Days (1982)



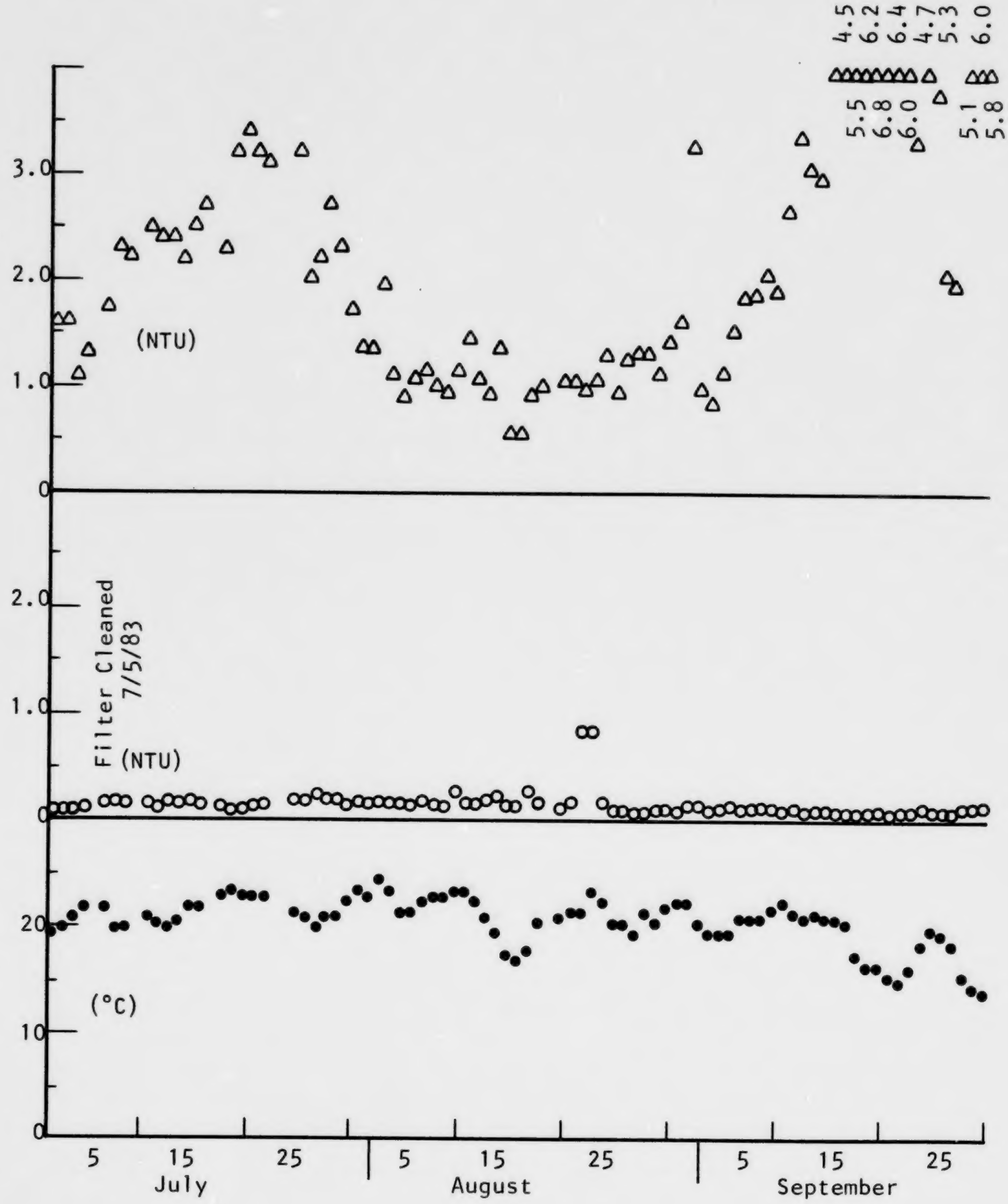
59
Rain
9.3
3.0
2.0
(NTU)
1.0
0
2.0
1.0
(NTU)
0
20
10
(°C)
25
Oct.
5
15
November
25
5
15
December
25
5
Jan.
(1983)
Time - Days (1982)



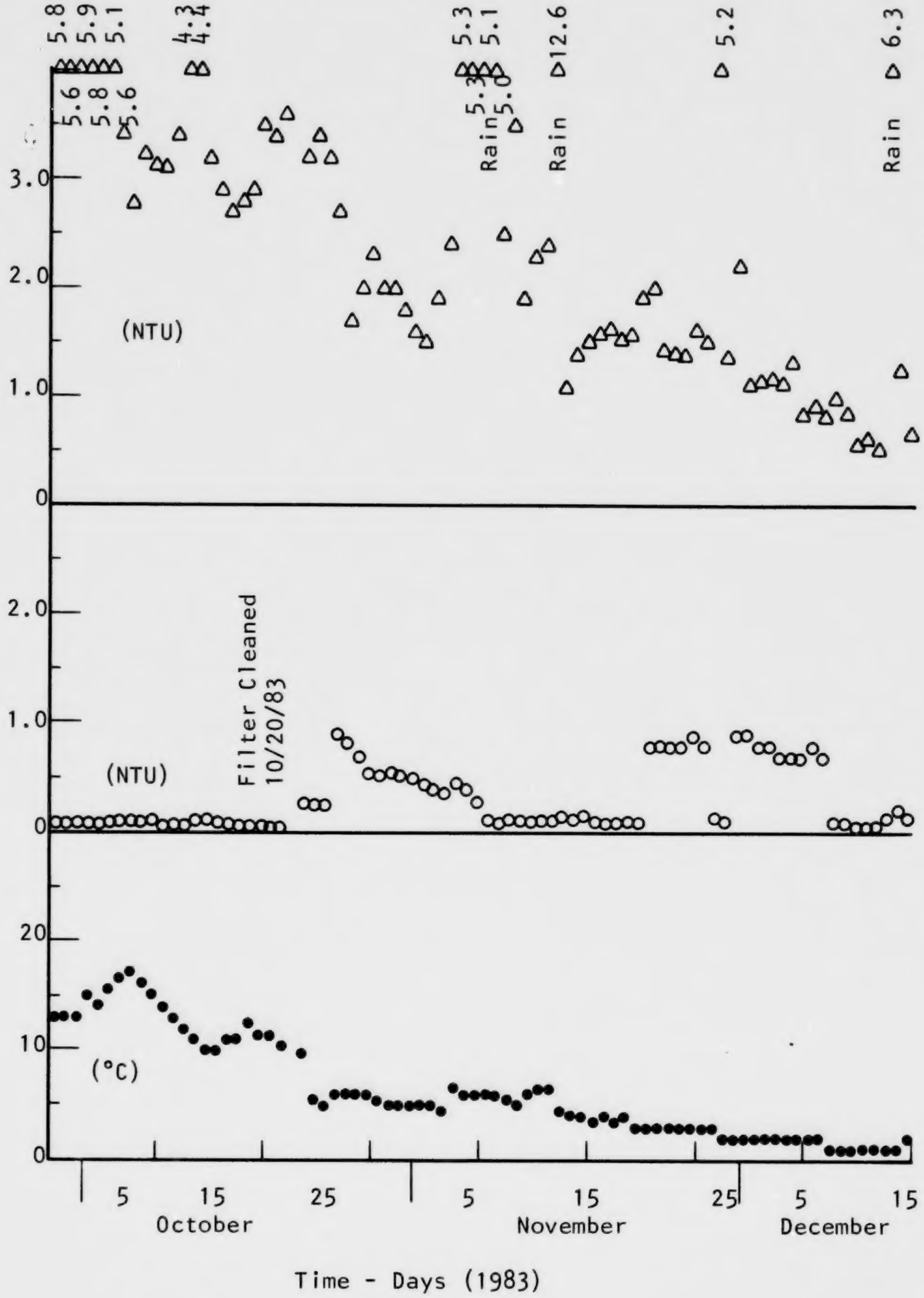
7.2
Rain
3.0
2.0
(NTU)
1.0
0
Rain
Rain
Rain
2.0
1.0
(NTU)
0
20
10
(°C)
0
Filter Cleaned 1/24/83
15
25
5
15
25
5
15
25
January
February
March
Time - Days (1983)

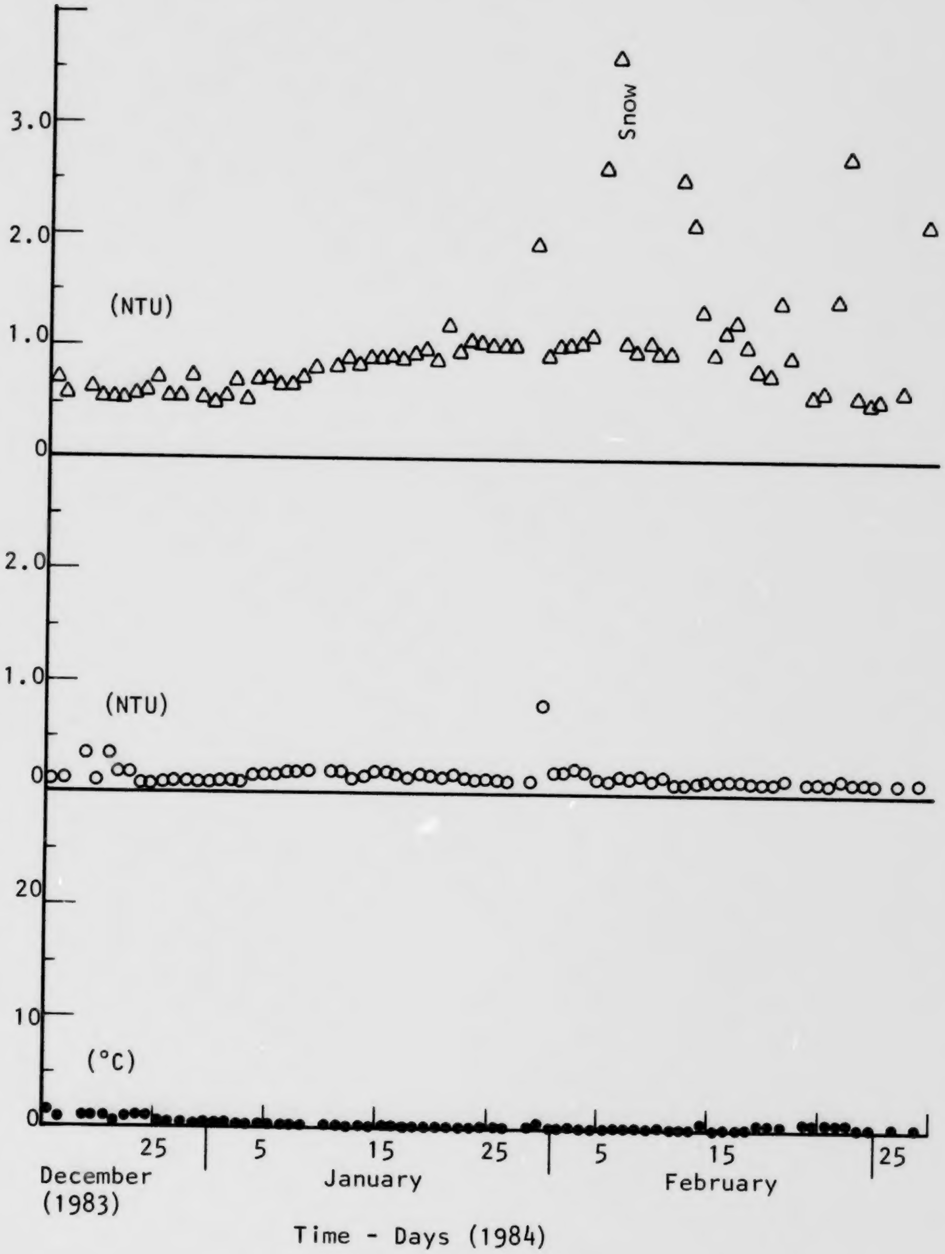


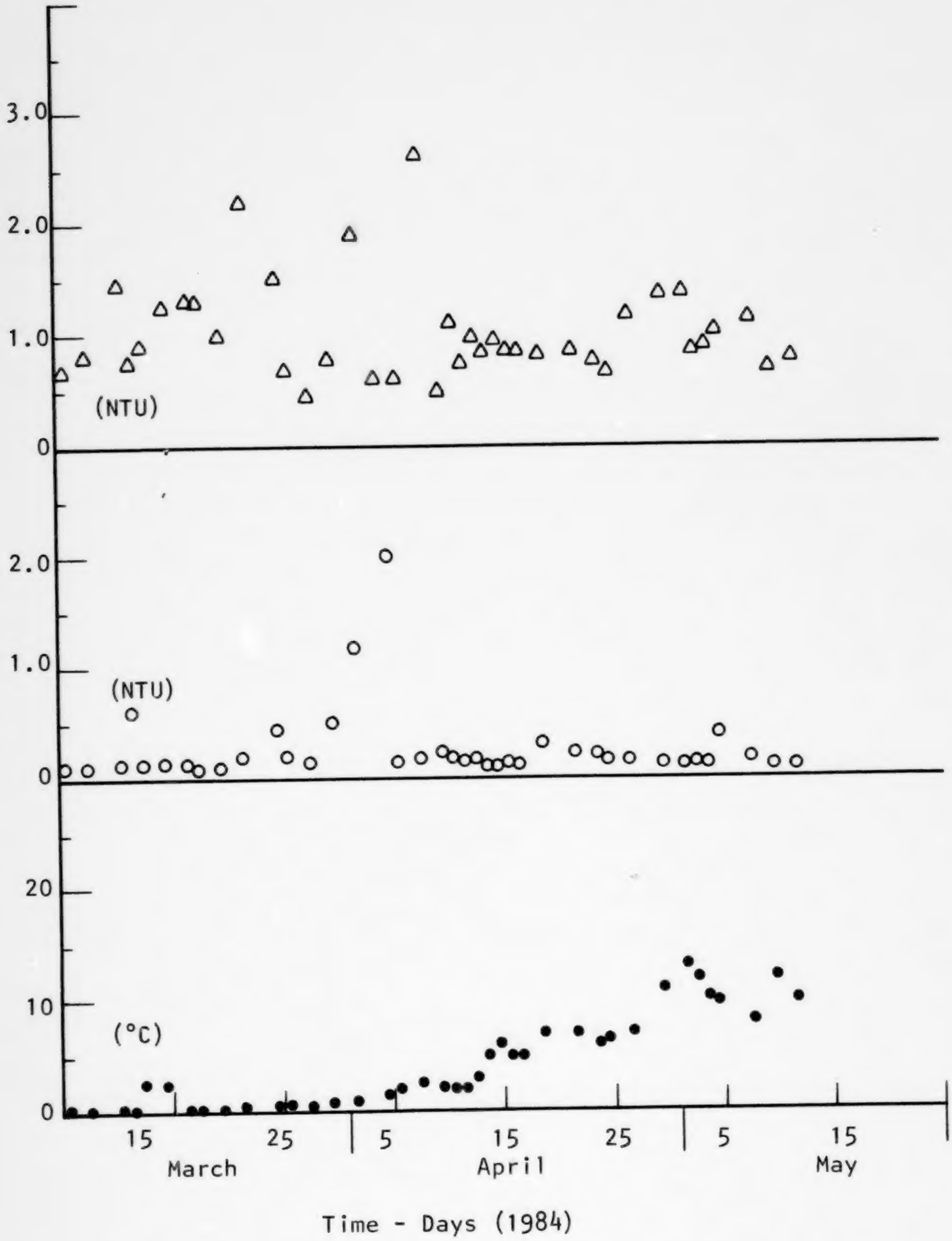
Rain
Rain
4.5
Rain
3.0
2.0
1.0
0
(NTU)
2.0
1.0
(NTU)
0
20
10
(°C)
0
15
25
April
5
15
25
May
5
15
25
June
Time - Days (1983)



Time - Days (1983)


5.8
5.9
5.1
4.3
4.4
5.3
5.1
12.6
5.2
6.3
5.6
5.8
5.6
5.3
5.0
Rain
Rain
Rain
3.0
2.0
(NTU)
1.0
0
2.0
Filter Cleaned
10/20/83
1.0
(NTU)
0
20
10
(°C)
0
5
15
25
October
5
15
25
November
5
15
December
Time - Days (1983)


3.0
2.0
1.0
0
(NTU)
Snow
2.0
1.0
0
(NTU)
20
10
0
(°C)
25
5
15
25
5
15
25
December
(1983)
January
February
Time - Days (1984)



3.0
2.0
1.0
(NTU)
0
2.0
1.0
(NTU)
0
20
10
(°C)
0
15
25
5
15
25
5
15
March
April
May
Time - Days (1984)

Figures 12 and 13 show the effect of cleaning on total coliform and standard plate count removal during this recovery (1/24/83 - 2/10/83). In this situation the total coliform reduction showed the worst degradation to 15% removal in one day recovering to 97% in nine days although there was some decrease in removal for a few days after apparent recovery. During this period of time the total coliform counts in the effluent ranged from 6/100 mL at the start to 70/100 mL in 3 days then the values fluctuated between 2 to 7/100 mL from 3 to 21 days after cleaning.

The standard plate count demonstrated much more pronounced degradation in percent reduction after cleaning (Figure 13). Removal went to -300% in one day recovering to 95% in nine days. The standard plate count effluent values were 160/mL in two days after cleaning to 1/mL in 13 days.

Turbidity was affected greatly by this cleaning. Figure 14 shows a decrease from an average turbidity removal of 85% to 49% removal immediately after cleaning with improvement to 92% removal in 10 days, but decreasing to 62% in 12 days and subsequently improving to 78% in 17 days. The turbidity values in the effluent increased from 0.15 NTU before cleaning to 0.4 NTU right after cleaning and reducing to 0.15 and less in 15 days.

Cleaning on October 20, 1983 was not studied extensively, thus little bacterial data could be used to evaluate the recovery effect. Turbidity changes were pronounced, changing from 0.05 NTU to 0.9 NTU in 4 days and decreasing to 0.1 NTU in 19 days after cleaning. There were some erratic values, 39 to 49 days after cleaning and then the effluent maintained 0.1 to 0.2 NTU most of the time. Figure 14 shows the reduction of turbidity during this (10/20/83) cleaning recovery with a very dramatic decrease in reduction and recovery in about 19 days. There was consistent reduction of about 98% before cleaning decreasing to 51% 5 days after cleaning and then improving to 96% in 19 days.

Recovery From Cleaning - Bacterial Spiking

The fourth cleaning recovery situation (7/15/83 - 7/27/83) studied involved cleaning and then sewage spiking. This study was envisioned to be the worst possible situation which could be encountered in filter operation. The filter would be the most vulnerable at this time and the bacterial load would be the worst possible, equivalent to sewage leakage or septic tank contamination.

Turbidity tended to rise in the influent during this recovery period but the rise was not the result of the sewage spiking. The effluent turbidity varied slightly but not significantly, from 0.1 NTU to about 0.2 NTU. The percent reduction of turbidity remained the same or even increased as shown by Figure 14. There was no sign of the filter being affected so far as turbidity was involved.

During this sewage spiking recovery period there was little evidence of disruption of the filter activity as shown by total coliform and standard plate count data (Figures 12 and 13). The number of coliforms in the effluent remained in the same range as before cleaning, 1 to 10/100 mL with a high value of 1200/100 mL which occurred before cleaning was performed. The total coliform reductions remained in the 99% range and the standard plate count also did not show any appreciable effect from the spiking and also remained in the 99% range. Before cleaning the filter the standard plate count effluent samples ranged from 2 to 12/mL and after cleaning they were 1 to 4/mL.

The percent reduction relationships for total coliform and standard plate count are strikingly evident when comparing influent and effluent as shown in Figures 15 and 16. In both cases the effluent is in the order of three orders of magnitude less than the applied concentrations.

This demonstrated the filter's ability to absorb a massive bacterial spike during warm weather operation. Cold weather spiking runs did not show the same ability for prolonged bacterial loading without some disruption of the filter and degrading effluent quality. If high organic loads were associated with the high bacterial spike the filter might have shown poorer results as the schmutzdecke might tend to become anaerobic. Dissolved oxygen was measured through the filter in the spring (5/16/84) at a water temperature of 10°C. There was a reduction of about 2 mg/L at that time and the effluent contained about 6.5 mg/L of DO.

Particle count data was obtained during the recovery from cleaning studies. The particle count information did not provide any real insight into recovery effects. The erratic fluctuations in percent removal were no greater than observed under normal operating conditions.

Table 28 summarizes the particle reduction relationships for several test conditions. The average percent reduction is the direct averaging of all values and is heavily weighted with negative values.

TABLE 28. PARTICLE REDUCTION - SLOW SAND FILTER (7 to 12 μm)

Test Method	Number Samples	Average % Reduction
Recovery from cleaning	28	50.6
Recovery from cleaning and sewage spiking	21	-8.1
Sewage spiking	42	32.4
Normal operation	62	44.6

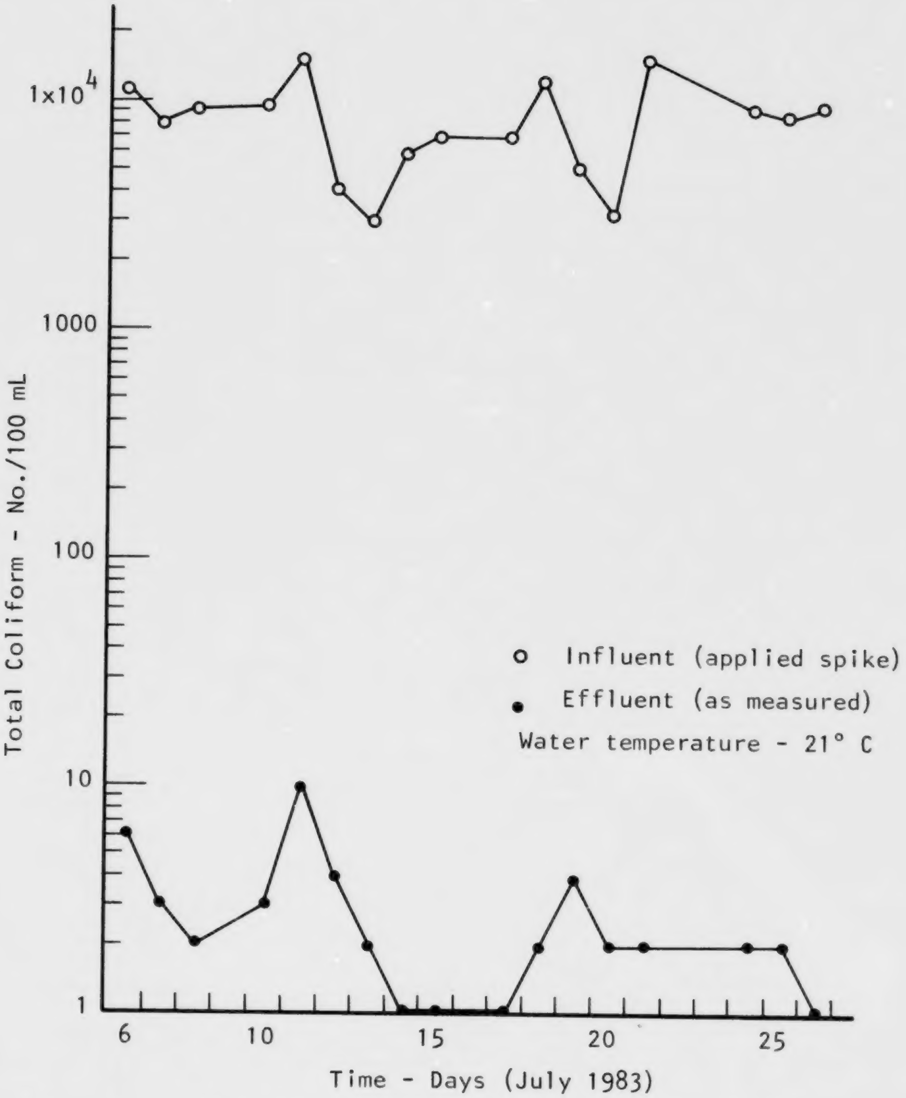


Fig. 15. Slow Sand Filter Recovery From Cleaning and With Sewage Spiking, Applied Total Coliform vs. Time - Filtration Rate 0.08 m/hr

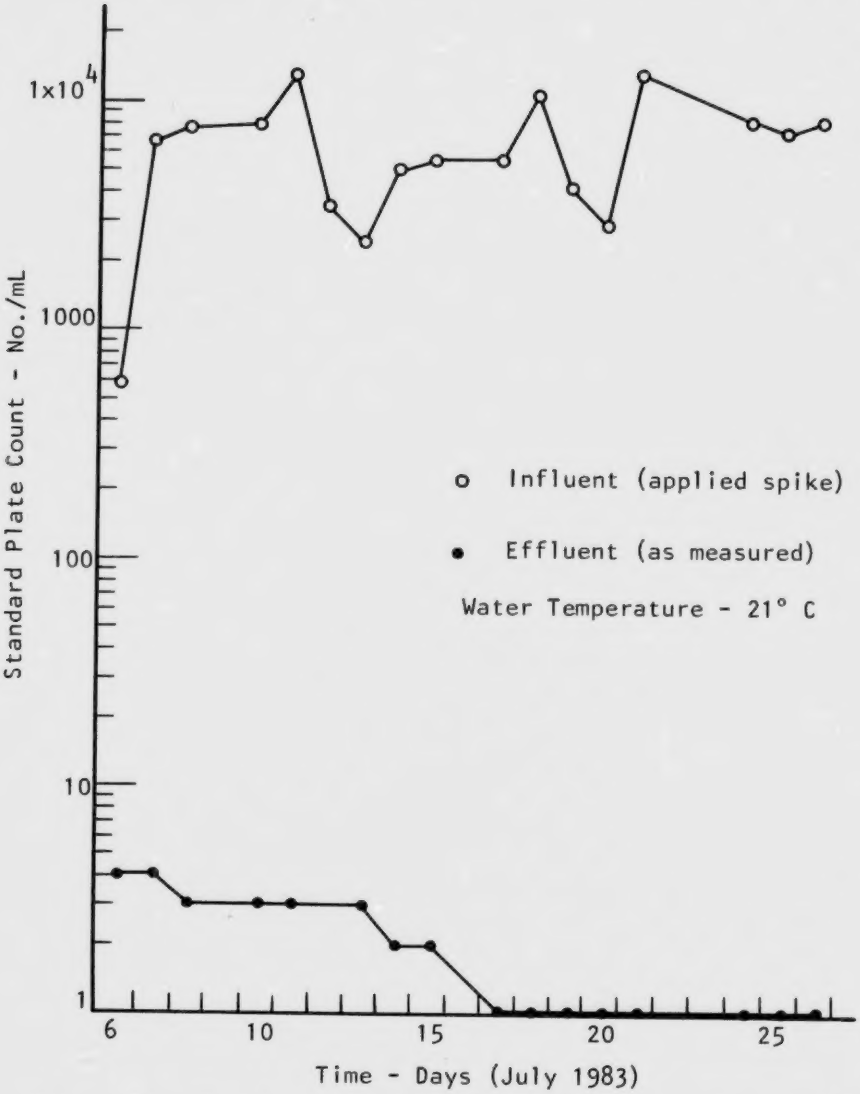


Fig. 16. Slow Sand Filter Recovery From Cleaning and With Sewage Spiking - Applied Standard Plate Count vs. Time - Filtration Rate 0.08 m/hr.

From Table 28 it is shown that normal operation and recovery from cleaning showed about the same percent removal although the average percent reduction was lower for normal operation than for the recovery situation. However, Figure 22 (page 107) shows that under normal operating conditions 50% of the effluent particle samples contained 2500/mL or less and 7500/mL or less in the influent. This shows an overall reduction of 67% (somewhat higher than the average) which indicates that there was little significant difference between the two situations and thus normal operation was in the range of 50 to 70% reduction and when recovering from cleaning only 50 to 60% reduction.

Sewage spiking did appear to have an effect on particle removal as shown in Table 28. When the filter was subjected to sewage spikes during recovery from cleaning the observed reduction was very poor regardless of the method of comparison, -8% removal. Some of the poor performance could be attributed to the inability to test for and calculate the particle load to the filter from the sewage being used for the spiking process. However, noncleaning recovery sewage spiking (normal operating condition) only showed a decrease of about 10% from (nonspiking) operation results and thus this demonstrated that during recovery from cleaning the filter was highly vulnerable to particulate loading. However, none of the Giardia cyst removal data demonstrated such low values and thus there appears to be little direct correlation.

Giardia Removal

Giardia cyst removal was studied under massive slug application conditions; between 2.1 x 10^6 per spike to 2.55 x 10^7 per spike. This loading was equal to about 35 cysts/L - 425 cysts/L (6 x 10^4 L water on the filter) in the filter water if the cysts were uniformly diluted at the time of application.

The cysts tended to appear in the effluent in maximum concentration within one to two days after the spike was applied. The percent reduction tended to be the highest during warm water conditions and poorest during cold.

Table 29 summarizes results of all the spikes applied to the slow sand filter. This table shows a maximum of 99.99% removal and a minimum of 93.7% removal. The maximum number of cysts calculated to be present in the effluent for 24 hr was 125,000 in 19,400 gal.

The number of cysts in the effluent tended to be a function of the number of cysts applied as shown in Table 29, particularly during cold water conditions. The data appear to show that the more biologically active filter under warmer water conditions the more cysts removed as contrasted to the less active winter filter. This characteristic is similar to the bacterial removal results.

The results obtained by these spiking studies provide the most severe test because the cysts were formalin treated and dyed for identification. Such treated cysts would tend to be much more resistant to biologic attack and physical damage than fresh viable cysts.

TABLE 29. SLOW SAND FILTER - GIARDIA CYST REMOVAL
FILTRATION RATE - 0.08 m/hr.

Spike Date	Sample Dates	Temperature °C	Cysts Applied	Days Since Most Recent Filter Scraping	Number of 24-Hour Samples Collected	Cysts Recovered On Sampling Filter	Total Cysts Passing Through Filter	Number of Samples With NO Cysts	Cyst Removal
2/28/83	3/1/83 - 3/6/83	0.5°	2.1×10^6	34	6	4032	132,000	3	93.7%
1/16/84	1/17/84 - 2/14/84	0.5°	2.55×10^7	88	26	3214	97,000	9	99.62
2/14/84	2/15/84 - 3/12/84	0.5°	2.31×10^7	117	26	3503	125,000	10	99.46
12/8/83	12/9/83 - 1/16/84	0.75°	2.3×10^7	50	38	4090	147,000	19	99.36
3/12/84	3/13/84 - 4/9/84	0.75°	2.55×10^7	144	28	485	23,000	2	99.91
4/9/84	4/10/84 - 5/11/84	7.5°	2.31×10^7	174	32	51	2,300	19	99.99
5/16/83	5/17/83 - 5/23/83	11°	2.1×10^6	82	7	8	420	6	99.98
8/8/83	8/9/83 - 8/12/83	21°	8×10^6	35	5	42	1,600	2	99.98

Cold water below 5 to 10°C tended to show the poorest removal or the more likelihood of cysts appearing in the slow sand filter effluent. It appears that the dividing point is about 5°C. Giardia cyst removal versus temperature is shown in Figure 17 and in the temperature range of 0.5 to 1.0°C the percent removal ranges from 99.36 to 99.91. In the range of observed temperature effects from 7.5 to 20°C removal was in the order of 99.98 to 99.99.

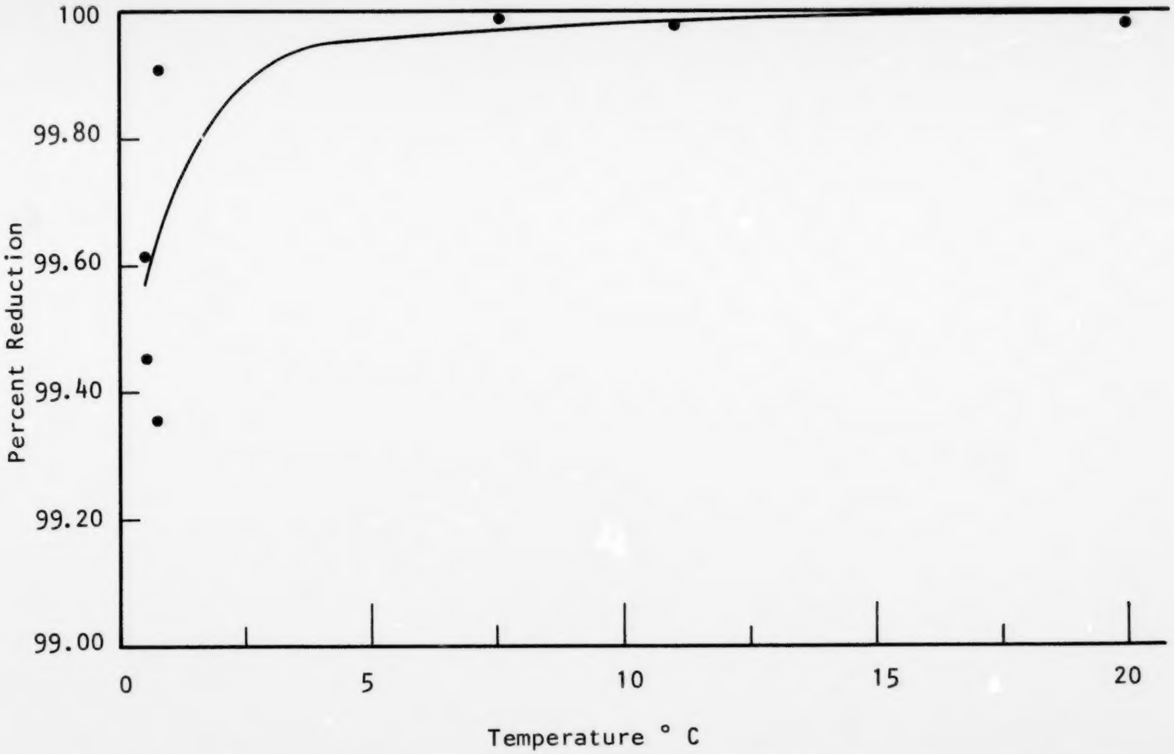


Fig. 17. Slow Sand Filter - Percent Reduction of Giardia Cysts vs Temperature - Filtration Rate 0.08 m/hr

Initially samples were only collected for 5 to 7 days as it was thought that most of the cysts appeared in the effluent within about 5 days. Some additional sampling indicated that at times cysts were appearing long beyond the time of a spike application. New studies were set up for long-term cold weather operation in order to more completely understand cyst appearance in the filter effluent, particularly during cold weather.

The results of the studies are summarized in Table 30 which shows that during cold weather cysts tend to appear up to 34 days after spike application. This indicates that apparent cyst removal for short sampling times might be somewhat higher than the true situation, if cysts challenged a slow sand filter only on an intermittent basis.

It would appear that cysts are retained in the filter bed or schmutzdecke and if not destroyed by biological or physical activity eventually may work their way through the filter. The warm weather results indicated very little of this type of drag-out as cyst removal was both higher, more consistent, and primarily occurred in the first few days during warm water temperature conditions.

Cyst removal summarized in Table 29 shows both the effects of water temperature and also shows that most of the runs were performed with a fairly mature filter, at least 30 or more days since last scraping of the surface.

The 93.7% removal obtained during the March 1983 spike study is considerably lower than other cold weather observations. This spike was conducted at the same time sewage bacterial loading spiking was being performed in order to simulate a Giardia cyst and sewage loaded application. During this particular spike study the bacterial results were affected by the sewage spiked bacteria, both total coliform and standard plate count. The bacterial reduction tended to deteriorate with time as the spike continued. Under these cold temperature conditions it would appear that the bacteria and Giardia cyst removal activity or functions are related and during the cold weather there is sluggish biological activity. It appears that the biological system becomes completely over loaded. The other four times when Giardia spiking alone was studied at temperatures under 1°C the percent reductions were lower than for warm water conditions, but were in the range of 99.36 to 99.91% removal. Anaerobic conditions during the cold weather and dilute sewage applications would not be expected to develop although dissolved oxygen was not measured for these studies. This shows that the most adverse time with respect to possibly obtaining a high degree of treatment with a slow sand filter is during extremely cold weather, unless extremely warm weather were to produce anaerobic conditions which could also disrupt the treatment process.

No cysts were recovered from the slow sand filter sand samples or schmutzdecke. This lack of recovery did not mean that there were not any cysts in the filter sand or the schmutzdecke. None of the separation techniques tried produced satisfactory separation and concentration of cysts from the associated background material. Recoveries were poor and the flocculant iron and organic background prevented effective microscope examination of the concentrate produced from the smaples. More extensive work would have to be done to find an approach to isolate and identify Giardia cysts from sand and sediment. The iron present in this sand may have contributed to the particularly difficult separation problem.

Bacterial Spiking

Two bacterial spiking studies were conducted to evaluate the removal of bacteria under massive bacterial loads using a well developed schmutzdecke and mature filter. Figures 18 through 21 show the results of such studies. For the first run shown in Figures 18 and 19 the filter had an average age since cleaning of 38 days and had been in operation since start-up as a relatively new filter for about 290 days. The second run (Figures 20 and 21) had an average age of 100 days since cleaning and since initial start-up, about 350 days.

The figures show that there was good removal for both total coliform and standard plate count in the second run, but there was not so much removal with time in the first run.

Figures 18 and 19 and Table 31 show that for the first run the total coliform and standard plate count effluent quality tended to deteriorate in about 9 days after spiking was started. In Table 31 the percent reduction of applied total coliform dropped to 43% and 82% for standard plate count at the end of the spiking period. The second run under warmer temperature conditions demonstrated remarkedly different results. The total coliform and standard plate count reductions (Figures 20 and 21 and Table 31) showed little sign of spiking impact. The applied coliform removal was 99.2% or better and the standard plate count was 92% or better except for one value of 77%, but this was not a permanent impact.

These figures and results demonstrate the filter's ability to absorb massive applications of bacteria in water temperature conditions of 5°C or more. Under colder conditions, water temperatures below 5°C the filter tended to produce poorer results and showed impairment of effectiveness after 9 to 10 days of constant spiking, resulting in disruption of the effluent quality even after the spiking stopped. In the warmer water conditions it was shown that there was no sign that even after 15 days of spiking there was any disruption of the effluent and no aftermath disruption. These results agree with the results obtained after cleaning and spiking at temperatures of 21°C, Figures 15 and 16.

TABLE 30. SLOW SAND FILTER - PERCENT OF TOTAL NUMBER OF *GIARDIA* CYSTS CALCULATED TO BE IN EFFLUENT/DAY

		Days from Spike									
Spike Date	Temp. °C	1	2	3	4	5	6	7	8	9	10
(1) 2/28/83	0.5	95.1	3.0	1.9	0	0					
(2) 5/16/83	11	100	0	0	0	0	0	0			
(3) 8/8/83	21	49.6	37.9	0	0	12.5					
(4) 12/8/83	0.75	18.3	45.2	20.9	6.9	2.4	1.7	0.9	1.8	0.5	0
(5) 1/16/84	0.5	28.3	52.4	11.5	3.0	1.0	0.8	0	0.2	0	-----
(6) 2/14/84	0.5	15.8	61.8	13.3	4.2	0	0.7	2.2	-----	1.2	0.3
(7) 3/12/84	0.75	2.9	-----	24.2	19.6	3.7	0.9	-----	2.3	-----	26.6
(8) 4/9/84	7.5	0	0	0	9.0	0	8.8	0	-----	0	-----

		Days from Spike									
Spike Date	Temp. °C	11	12	13	14	15	16	17	18	19	20
(4) 12/8/83	0.75	-----		0.3	0.1	0.1	0.1	0.2	0	0	0
(5) 1/16/84	0.5	0.5	-----	0.3	0.2	0.2	0.5	0	0	0	0
(6) 2/14/84	0.5	0	0.2	0	0.2	0.2	-----	0	-----	0	-----
(7) 3/12/84	0.75	-----	-----	4.5	1.6	-----	0.5	-----	3.4	-----	1.1
(8) 4/9/84	7.5	-----	13.4	-----	0	0	-----	0	-----	-----	19.8

TABLE 30 (continued)

		Days from Spike									
Spike Date	Temp. °C	21	22	23	24	25	26	27	28	29	30
(4) 12/8/83	0.75	0	0	0	0	0	0	0.2	0	0.1	0
(5) 1/16/84	0.5	0.2	0	0	0	0.2	0	0	0		
(6) 2/14/84	0.5	0	-----	0	-----	-----	0.1	0	0		
(7) 3/12/84	0.75	-----	0	-----	5.6	-----	2.1	-----	1.0		
(8) 4/9/84	7.5	-----	0	-----	11.9	-----	-----	-----	37.1	-----	-----

		Days from Spike								
Spike Date	Temp. °C	31	32	33	34	35	36	37	38	39
(4) 12/8/83	0.75	0.1	0	0.1	0	0	0	0	0	0
(5) 1/16/84	0.5									
(6) 2/14/84	0.5									
(7) 3/12/84	0.75									
(8) 4/9/84	7.5	-----	0							

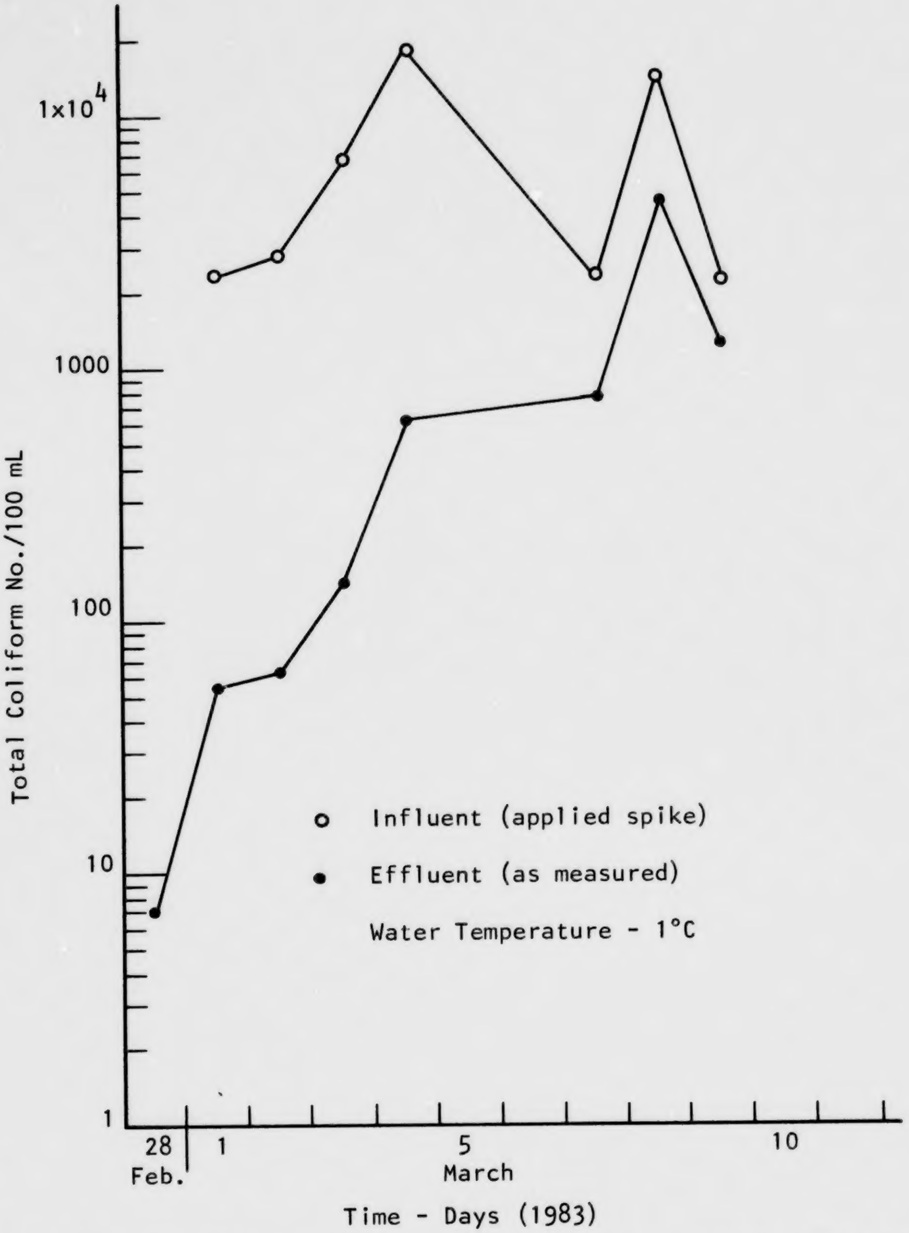


Fig. 18. Slow Sand Filter - Sewage Spiking - Total Coliform vs Time - Filtration Rate 0.08 m/hr

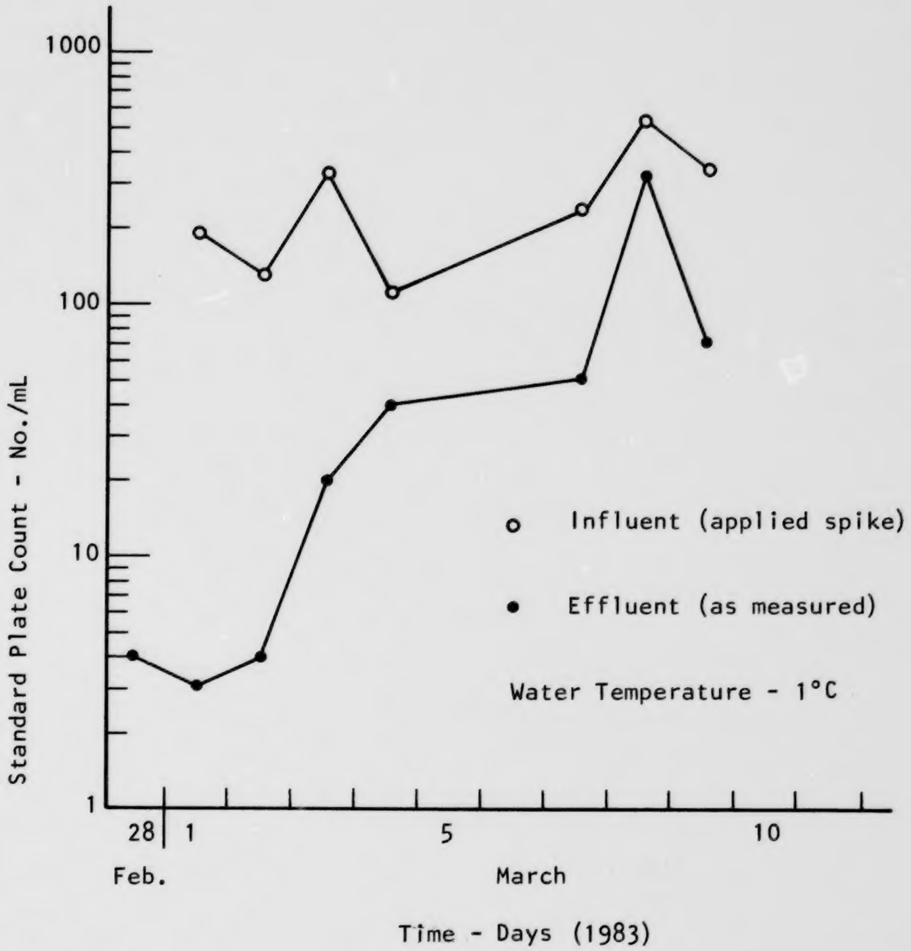


Fig. 19. Slow Sand Filter - Sewage Spiking - Standard Plate Count vs Time - Filtration Rate 0.08 m/hr

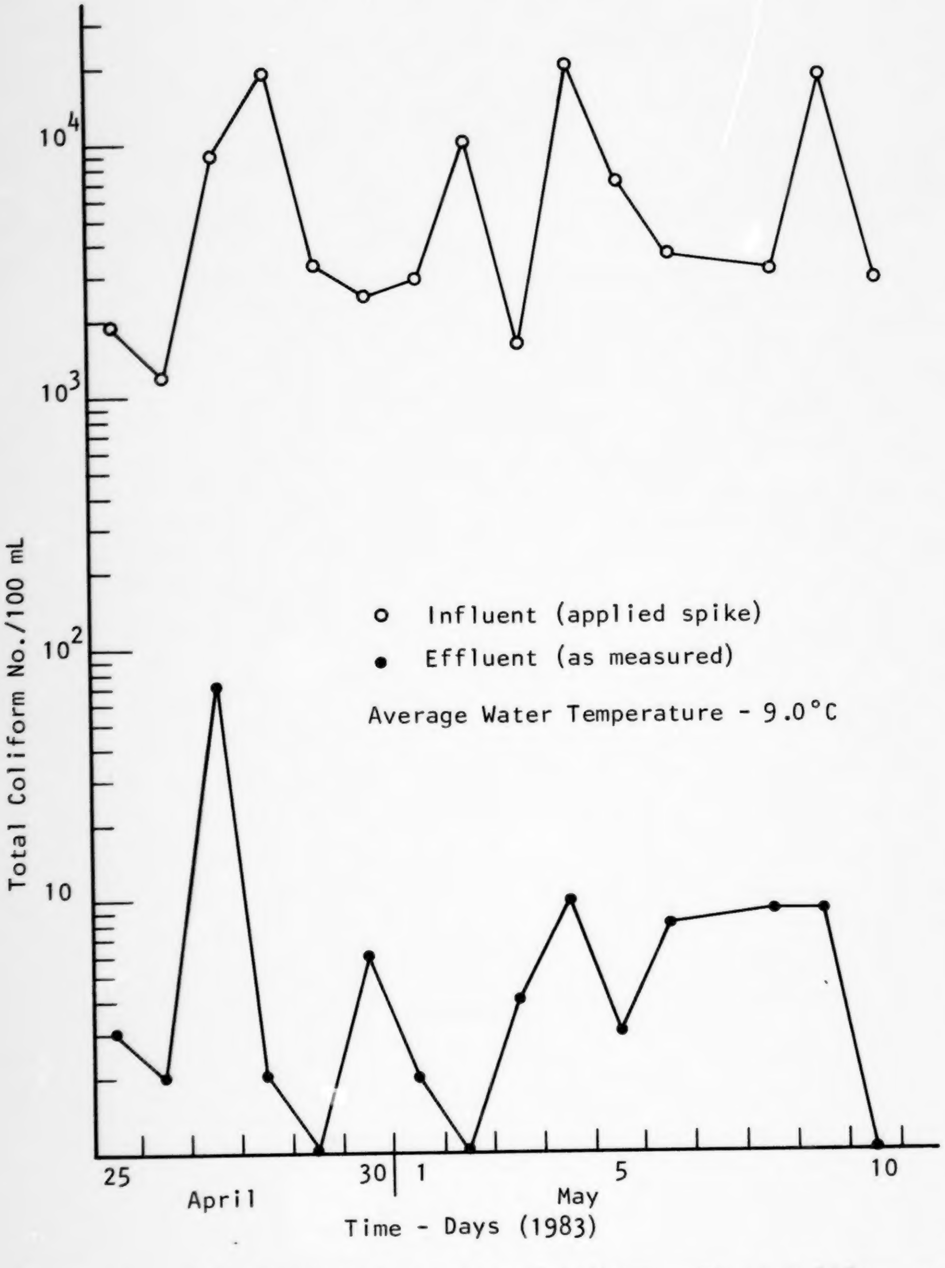


Fig. 20. Slow Sand Filter - Sewage Spiking - Total Coliform vs Time - Filtration Rate 0.08 m/hr

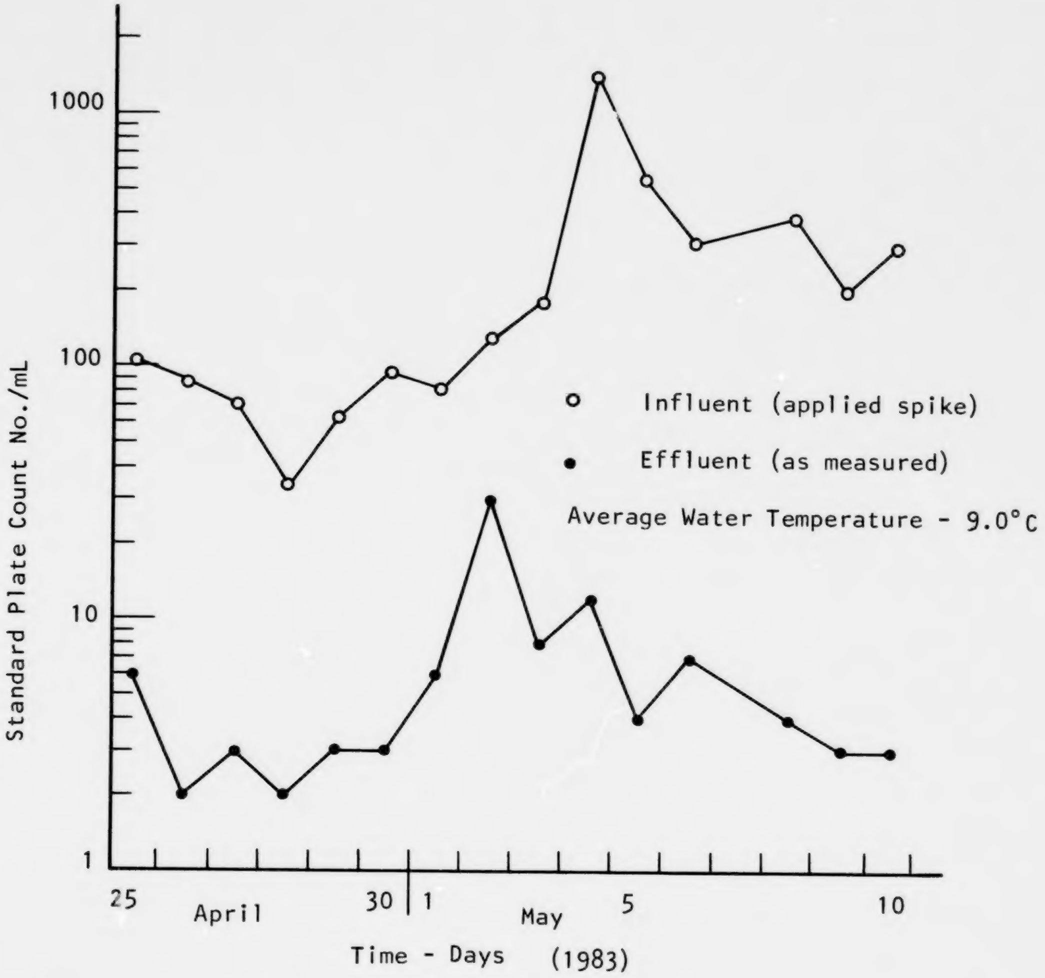


Fig. 21. Slow Sand Filter - Sewage Spiking - Standard Plate Count vs Time - Filtration Rate 0.08 m/hr

The applied bacterial values shown in Figures 15 and 16, 18 through 21 and Table 31 were calculated based on raw water bacteria and the bacterial concentration and volume of sewage spiked. The applied value was corrected for die-off or increase of bacteria depending on the temperature conditions under which the spiking occurred. This correction was obtained by running studies in the laboratory to determine the effects of temperature on the stored sewage.

Particle Reduction - Normal Operation

Slow sand filter effluent and influent particles in the 7 to 12 µm range were recorded and results summarized for normal ambient conditions in Figures 22 and 23. The reductions obtained under ambient conditions (6/18/82 through 5/4/84) were an average of 45% with a maximum of 99.5% and a minimum of -220.5%, for 62 observations.

However, the particle relationships were very erratic as shown by Figure 22. Fifty percent of the influent sampled contained 7000/1 mL or more and the effluent contained 2500/1 mL or more, a reduction of 84%. But frequently there were negative reductions as well as very low reduction values. Some of the effects were the result of low values in the raw water following high values. However, many of the high effluent values were the result of filter sloughing biological organisms and fine inert particulate matter(mostly sand). Microscopic examination conducted during Giardia cyst studies indicated that there were rotifers, algae such as Chlorella and other organisms as well as sand and quartz appearing materials in the slow sand filter effluent.

There was some improvement in the effluent particle content in the 7 to 12 µm range studied as shown in Figure 22. This figure relates the particle concentration distribution for all the normal operation samples tested and provides a better indication of the particle water quality and reductions. The water quality was improved by passing through the filter, but this was the poorest improvement of any parameter other than total trihalomethane precursors. From Figure 22 the overall particle improvement in the effluent is about 70%. This value is higher than the average, but negative reductions and extreme fluctuations affect the average calculation. Figure 23 shows the relationship of the range of the percent of samples showing the indicated percent reductions. This figure shows that 50% of the samples had about 70% or better reduction in particles and from Figure 22, 50% of the effluent samples had less than 2500 particles per 1 mL but only 20% had less than 1000 per 1 mL at a reduction (Figure 23) of 30% or less or 80% of the samples only showed 30% or better reduction, a rather poor showing.

TABLE 31. SLOW SAND FILTER - BACTERIA SPIKE STUDIES

Date	Water Temp. °C	Percent Reduction Total Coliform Applied	Percent Reduction Standard Plate Count Applied
Run 1 2/28/83 - 3/9/83			
2/28/83	1		
3/1/83	1	97.8	98.4
3/2/83	1	97.6	96.9
3/3/83	1	97.9	93.9
3/4/83	1	96.4	96.4
3/7/83	1	67.0	78.8
3/8/83	1	67.9	93.8
3/9/83	1	42.7	82.0
Run 2 4/25/83 - 6/1/83			
4/25/83	6	99.84	94.23
4/26/83	6	99.83	97.70
4/27/83	6	99.20	95.71
4/28/83	6	99.99	94.11
4/29/83	8	99.97	95.23
4/30/83	10	99.76	96.81
5/1/83	11	99.93	92.59
5/2/83	10	99.99	76.92
5/1/83	11	99.75	95.60
5/4/83	11	99.95	99.14
5/5/83	11	99.96	99.27
5/6/83	11	99.78	97.74
5/8/83	11	99.71	98.97
5/9/83	10	99.95	98.50
5/10/83	9	99.96	99.00

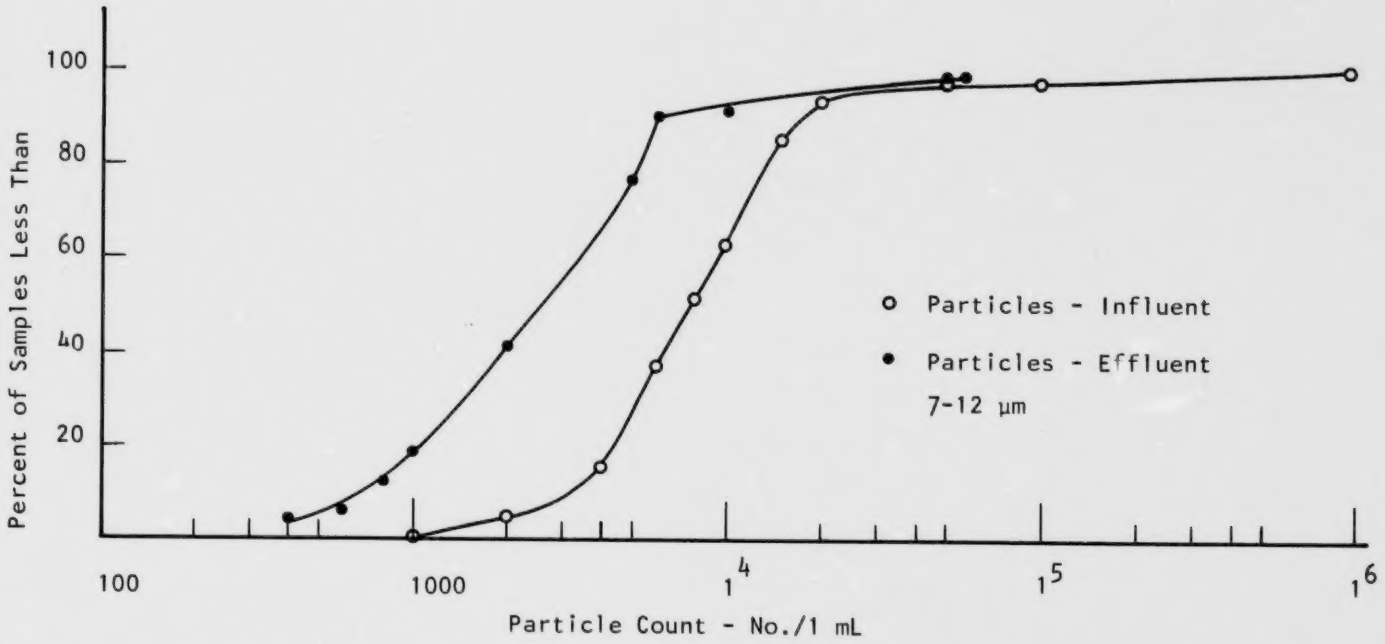


Fig. 22, Slow Sand Filter - Observed Occurrence of Particles in Influent and Effluent, Normal Operation - Filtration Rate 0.08 m/hr

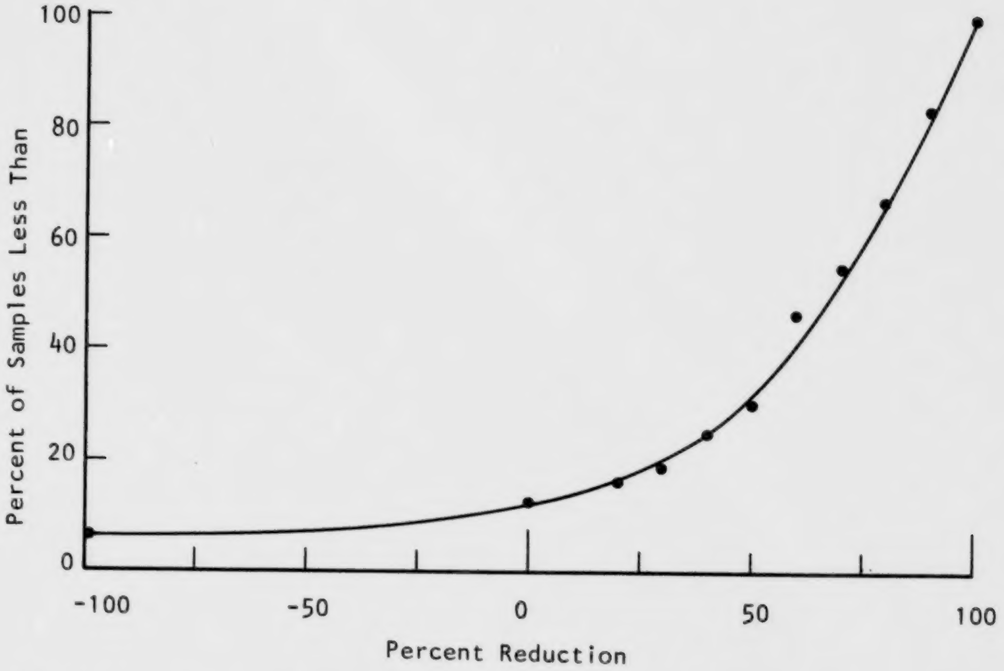


Fig. 23. Observed Occurrences of Percent Reduction of Particles (7-12um) in Slow Sand Filter, Normal Operation - Filtration Rate 0.08 m/hr.

One objective in studying particles in the 7 to 12 µm range was to evaluate the potential for Giardia removal, which has a size range of 7 to 12 µm. For this filter, the particle information does not offer great promise, however, the nature of the observed particles in the effluent indicate that for this filter and the collected data a direct correlation cannot be made. There appears to be little relationship between particles loaded onto the filter and particles out of the filter.

Turbidity Reduction

Influent and effluent slow sand filter turbidity was monitored continuously during the study. The range of results is shown in Table 32. The raw or influent water values were generally low with an average of 1.4 NTU, however, there were some high spikes as shown by the maximum value of 59 NTU. Such high influent turbidity values generally did not last for more than a day and did not produce obvious increases in the effluent turbidity. The influent values were very erratic but the effluent values were generally constant or only changed slowly, except after filter cleaning.

TABLE 32. SLOW SAND FILTER - TURBIDITY (NTU)

Sample Point	Number of Observations	Average	Maximum	Minimum
Influent	674	1.4	59	0.2
Effluent	701	0.22	8.0	0.05

The average effluent turbidity shown in Table 32 of 0.22 NTU is not as low as might be desired but represents an average turbidity reduction of 84%. The high value of 8.0 NTU only occurred once and there were practically no values which were anywhere near as high as this one reading. Figure 24 shows the distribution of turbidity samples for the filter influent and effluent. This figure shows that 50% of the samples had a turbidity of 1.0 NTU or less in the influent and 0.1 NTU or less in the effluent. The average improvement in turbidity quality was about 88%, slightly higher than the average from Table 32. This is to be expected as the average value from the table is affected by the extreme values. In the effluent 99% of the samples contained 1.0 NTU or less and thus 1% did exceed 1 NTU (MCL). Of the 1% greater than 1.0 NTU only 4 exceeded 1.4 NTU. Three of these four values occurred during the first 100 days when the unused filter was placed back in operation. One unexplainable high value occurred in April of 1984; value was rechecked at the time.

Head Loss

The operation of the slow sand filter was observed after cleaning for runs of 100 to 250 days at the filtration rate of 0.08 m/hr. The results of the head loss changes during the runs are shown in Figure 25 with respect to the length of each filter run.

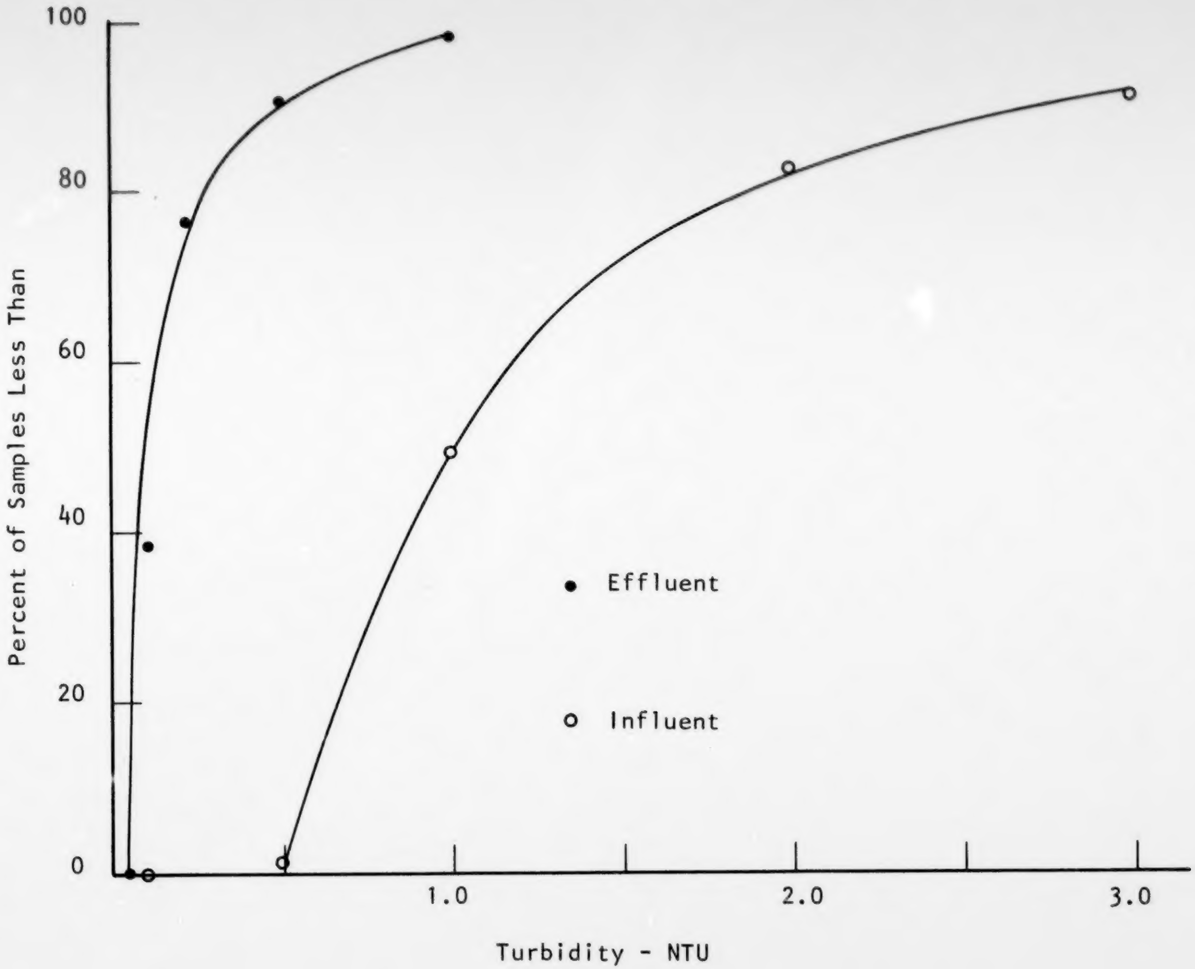


Fig. 24. Slow Sand Filter - Observed Occurrences of Turbidity, Normal Operation Filtration Rate 0.08 m/hr

The figure shows no consistency in filter head loss to length of run. Two runs (A) and (C) showed a tendency to develop exponential head loss increases after 100 to 150 days of operation. Run (B) exhibited a constant head loss trend if not even a decreasing trend with time and run (D) followed a linear head loss relationship up to 35 cm of loss at 210 days. These results indicate that for this filter a run of 100 days could be expected with some runs possibly extending to one year or more. Cleaning could be expected to occur between one and three times per year.

The maximum desired head loss for this filter is 135 cm, the low water depth over the sand surface. Extrapolation of the trends shown in Figure 25 would indicate that possibly run (D) could have proceeded for 810 days (2.2 yr) and run (B) might have proceeded indefinitely although it is conceivable that this run could be considered as the initial part of run (C) and thus might have been only 260 days in length. Run (A) reached 135 cm in 233 days and run (C) would have reached the head loss limit in 135 days.

These variations could have been the result of many factors such as effectiveness of cleaning, time of year cleaned, types of organisms, and organic material present, particularly with season. Iron was shown to be present in various quantities from 0.02 to 1.5 mg/L in the raw water. Iron was observed to have accumulated on the surface of the sand in the filter schmutzdecke. The amount of iron available in the raw water and the rate of accumulation on the filter could be a major contributor to head loss changes. Extensive chemical analyses would have been necessary to help define the cause of such changes and such determinations were not conducted as they were not within the scope of the project. The roughing filter inlet system appeared to provide some reduction in organic material and iron. However, it did appear that there was a considerable amount of both being applied to the filter from time to time.

Another interpretation of Figure 25 is that if the data were plotted consecutively there might be an indication of a long-term filter clogging effect. Run (D) tends to be higher in head loss sooner than the previous runs. Such a clogging trend could be the result of the iron tending to penetrate deeper and deeper into the filter. This research could not establish whether the filter may eventually reach a point of complete clogging and thus require sand replacement, either new or completely washed.

Trihalomethane Precursor Reduction

Chlorine demand was determined on the raw water before and during total trihalomethane (TTHM) formation studies. Figure 26 shows the variation in demand for four determinations, two in summer months, and two in winter months. All determinations demonstrated an instantaneous demand (within three hours) of about 4 mg/L with one summer demand as high as 10 mg/L. The winter demand values appeared to be more consistent and reproducible than the summer values with an ultimate demand of about 10 mg/L.

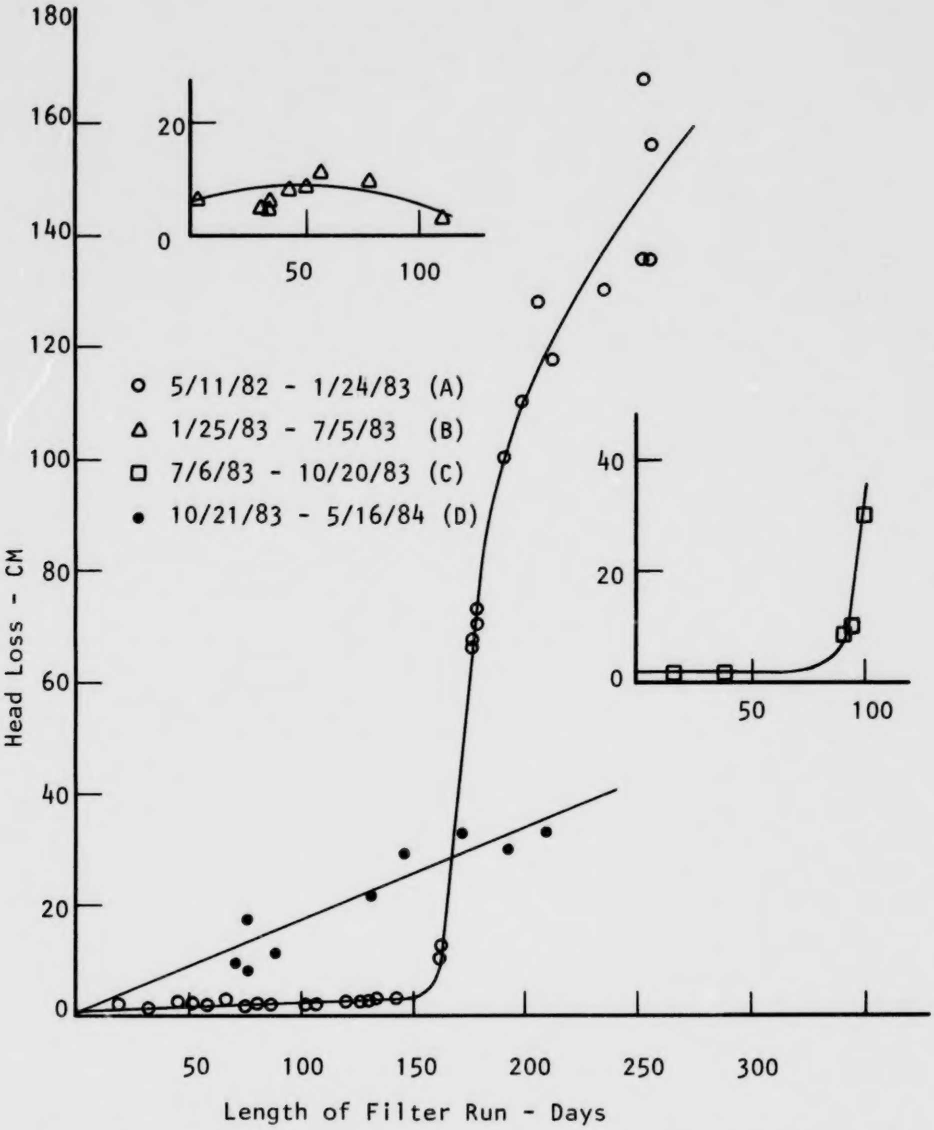


Fig. 25. Slow Sand Filter Head Loss vs Length of Filter Run at 0.08 m/hr

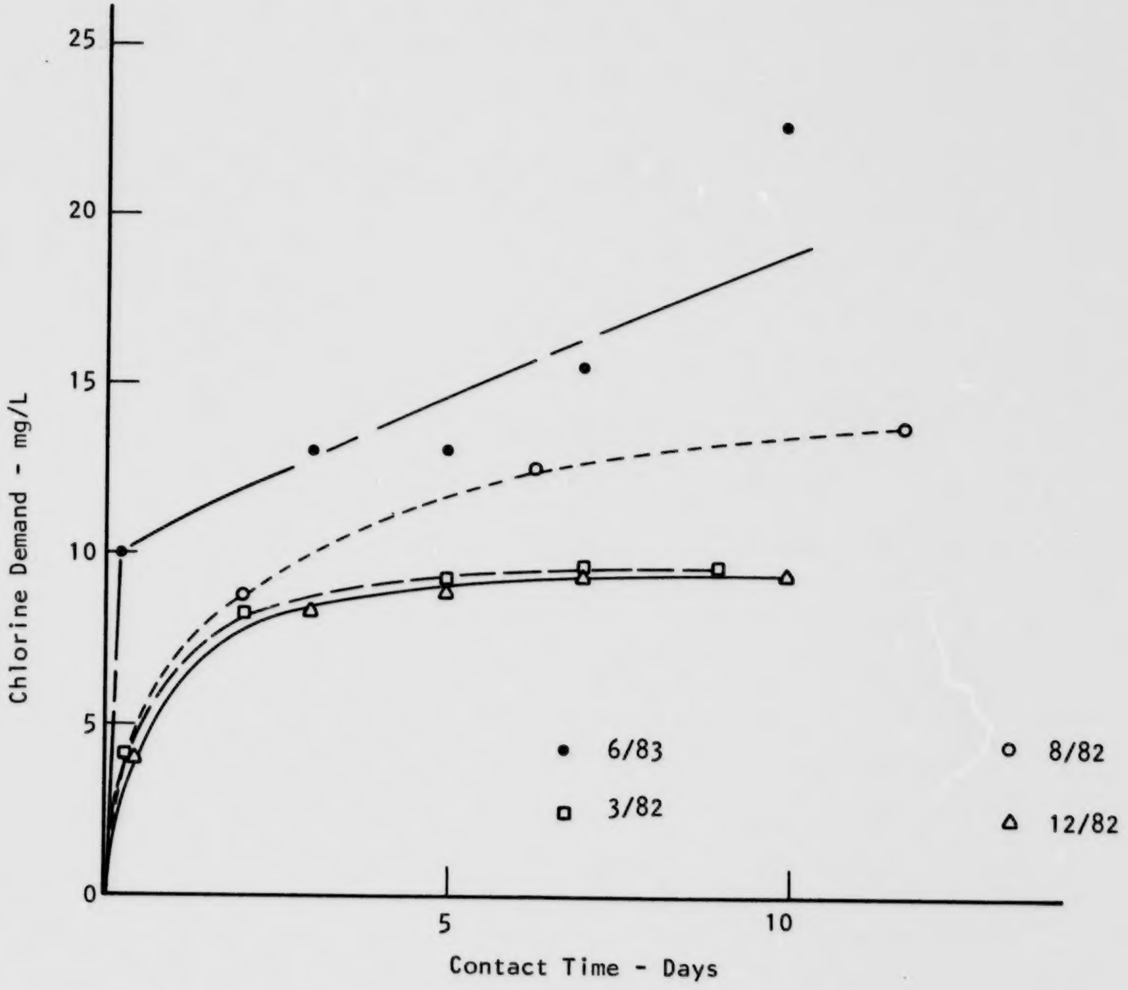


Fig. 26. Chlorine Demand VS Contact Time for Raw Water

The summer demand values were higher than winter and much more variable. The ultimate demand did not appear to be reached in 10 days of contact time for the summer samples. The 10-day residual values ranged from 14 to 23 mg/L.

TTHM formation study results are shown in Figures 27 to 29 with a composite in Figure 30. Figure 27 shows the formation of TTHM in raw water with an instantaneous (within 3 hr) value of about 30 ug/L increasing to an average of about 160 µg/L. The summer values appeared to be higher than for winter months. Tests on the raw water indicated that the maximum natural TTHM was about 5 µg/L of and thus no appreciable correction was necessary in the formation studies.

The results of the slow sand filter effluent TTHM formation are shown in Figure 28 for winter and summer water. The instantaneous formation of trihalomethanes was about the same as for the raw water and in 10 days the values were also about the same as the raw water.

A similar formation study was conducted on the (DE) effluent and the results demonstrated similar characteristics. Figure 29 shows the results of the DE effluent formation. The only difference from the raw and slow sand filter effluent results is the appearance that at the end of 10 days the TTHM tended to be higher than the raw water and the slow sand filter values. This would appear to be mostly the result of the time of year when this one run was performed, all parameters tended to be higher at that time.

A composite of averaged TTHM values is shown in Figure 30. This figure shows the results of the slow sand filter and DE filter formation studies and compares them with the raw water. The slow sand filter appears to have possibly reduced the TTHM precursors by about 10%. With the limited data and the variability in results this reduction cannot be considered as a significant or even true reduction. The apparent increase in DE effluent values is again not in a significant range and does not represent a meaningful increase. This summary in essence indicates that neither method of treatment demonstrated any meaningful reduction in TTHM precursors. The slow sand filter may have shown a 10% reduction.

These results indicate that it would be desirable to consider chloramine treatment for slow sand filter and DE filter effluents for water with high chlorine demand and TTHM formation potential. However, such a method of treatment could complicate the water treatment process for very small systems. Complication can be counterproductive and not produce as much protection to the water user as simple systems even though the simple system may not be as effective.

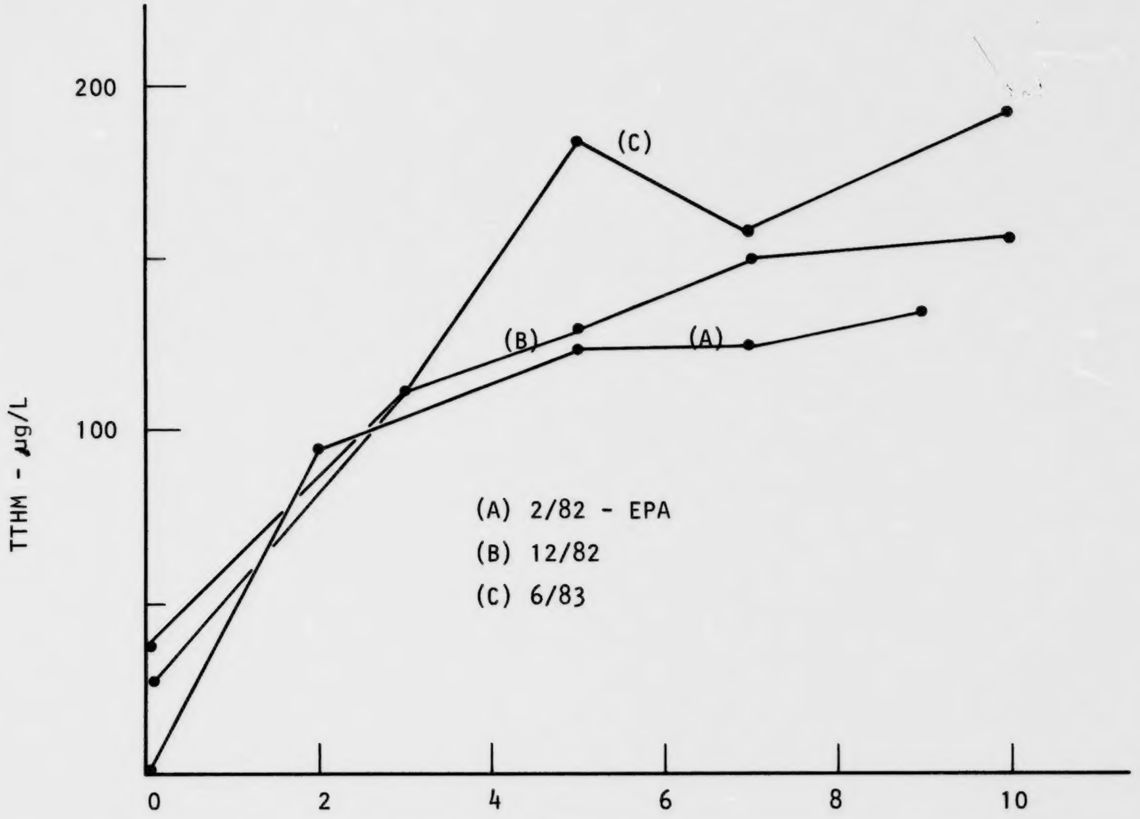


Fig. 27. Total Trihalomethane Formation in Raw Water VS Chlorine Contact Time

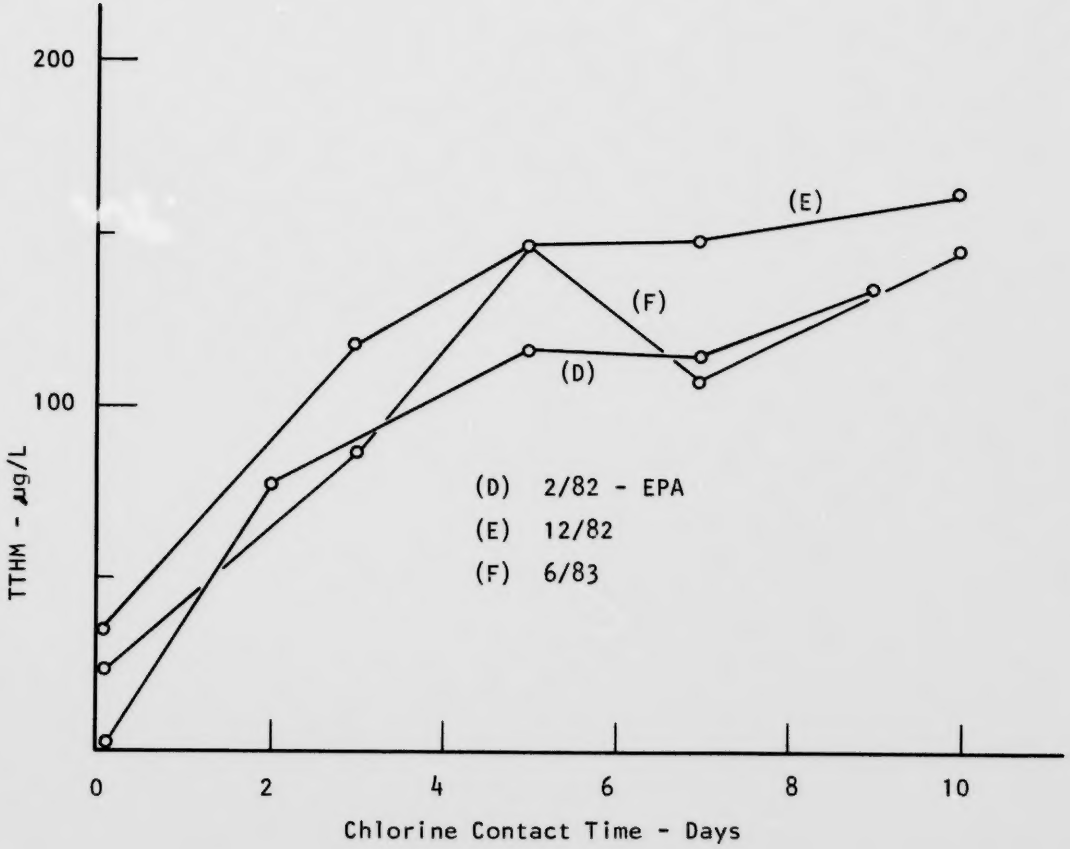


Fig. 28. Total Trihalomethans Formation in Slow Sand Filter Effluent VS Chlorine Contact Time

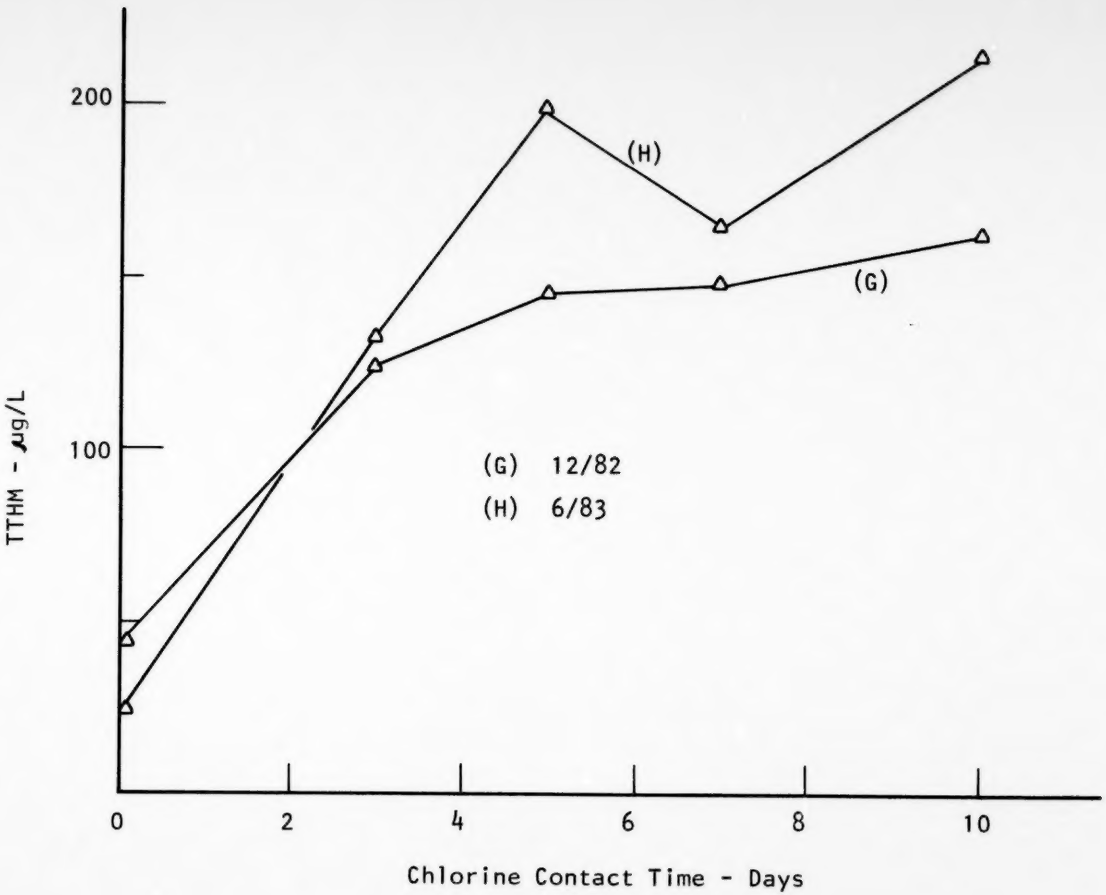


Fig. 29. Total Trihalomethane Formation in DE Filter Effluent VS Chlorine Contact Time

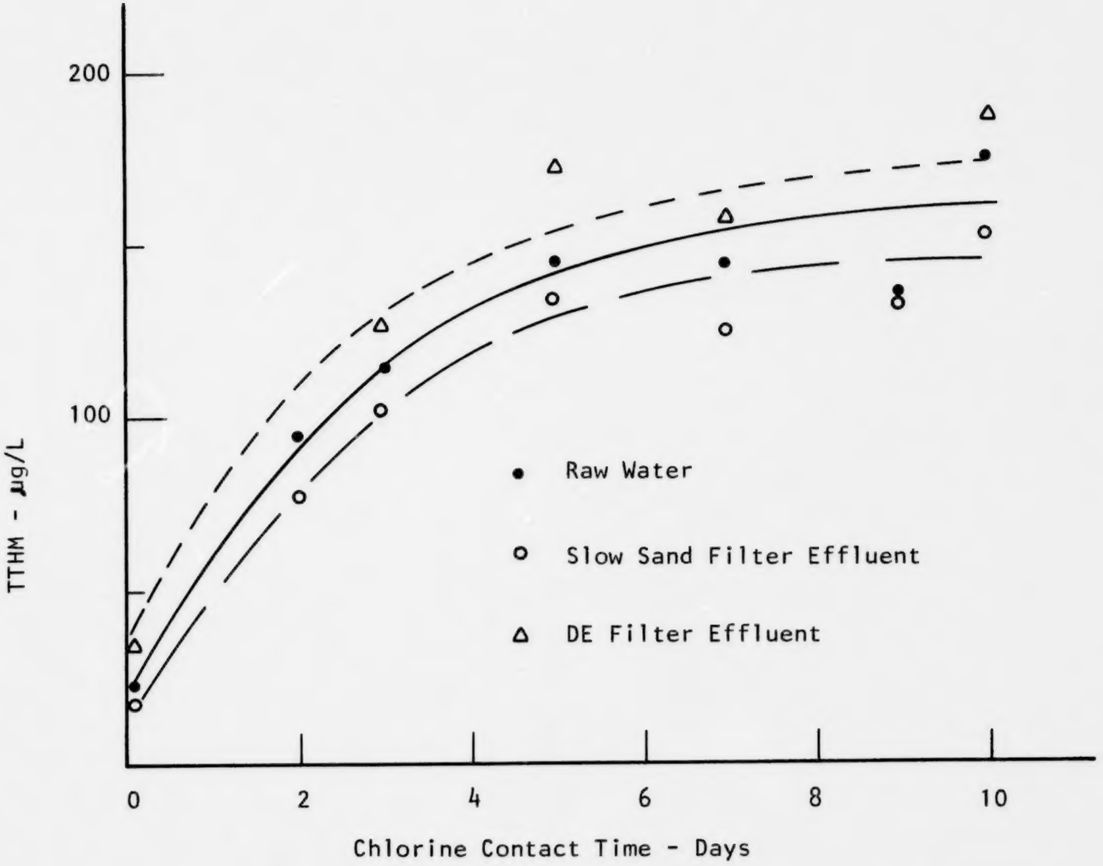


Fig. 30. Total Trihalomethane Formation VS Chlorine Contact Time - Composite Results

DIATOMACEOUS EARTH FILTER

Bacterial Removal

Bacterial studies were conducted involving 25 runs, mostly on the 10 ft^2 (0.93 m^2) septum unit using Celite 503.® Ten other pressure and body feed runs were performed using Celite 503® and two (run numbers 37 and 38) using Celite 512.® The summary of the run rates and ranges are shown in Table 40. This shows that the maximum variation in run rates was -17% to +13% of the mean. Much of this variation was the result of the tendency of the rotameter to stick and thus adjustments were not always obvious in the middle of the run. Also the raw water pump pressure-discharge function tended to affect the higher filtration rates. This also limited the pressure build-up for particular runs. In general the runs were not conducted much beyond 30 psi because the pump capacity began to be affected by pressure beyond this point. The few high pressure runs (up to 60 psi) tended to show reductions in rate as they approached the higher pressures.

TABLE 33. DE FILTRATION RATES

Type Run	Number Runs	Filtration Rate (m/hr) Mean	Maximum	Minimum
Bacteria & Particles	17	2.4	2.7 (+12.5%)	2.0 (-16.7%)
Bacteria & Particles	13	4.2	4.7 (+11.9%)	3.8 (-9.5%)
Variable Body Feed	7	2.5	2.6 (+4.0%)	2.4 (-4.0%)
Variable Body Feed	4	4.5	4.7 (+4.4%)	4.3 (-4.4%)
Celite 512®	2	2.6	2.6	2.6

The bacterial work in these studies was conducted using ambient bacterial conditions and also bacterial spiking. During the 25 bacterial studies pressure and run time data were recorded. Typical results of these observations are shown in Figures 31 through 35. At the start-up of various study runs the starting pressure tended to be higher for the high rate runs and lower for the low rate runs. However, there was considerable variation in start-up pressure conditions as shown in Table 34. From this table it is found that the filter runs started at a mean pressure of 3 psi for 2.4 m/hr. rates to 9.5 psi at 4.2 m/hr. filtration rates. The uncertainty as to the thoroughness of septum cleaning may have influenced the start-up pressure condition. This uncertainty and the possibility that iron might have been present at times may have contributed to some of the high starting pressures.

TABLE 34. DE FILTER PRESSURE AT START OF RUN

Mean Filtration Rate	No. Runs	Mean psi	Maximum psi	Minimum psi
		Celite 503®		
2/4 m/hr	21	3.1	5	0
4.2 m/hr	15	9.4	13	0
		Celite 512®		
2.6 m/hr	2	5	5	5

In Figures 31 through 34 it appears that the pressure tended to build up faster at the high filtration than at the lower filtration rates, but with considerable variation in values. However, this trend was also confirmed in the variable rate runs shown in Figures 32 and 35. These figures show that on the reduction from high rates (average of 4.2 m/hr) to low rates (average 2.4 m/hr) and those runs in which there were increases from low rates up to high rates the rates of pressure change were similar to the constant rate runs at the respective pressures. The low and high rate relationships are summarized in Table 35 for the variable rates wherein the mean pressure rate change for high filtration rate value is about 1.5 times that for the low value for a high to low filtration rate ratio of 1.8. This indicates that the rate of pressure build-up tended to be less than the rate of filtration increase.

In the later runs, such as in Figure 34, the pressure increase with time tended to be more exponential than in the first runs (1 through 11). These later studies were conducted at the same DE body feed concentrations which produced the desired straight line increasing pressure relationship. The exponential characteristic would indicate that body feed was too low. Additional studies were conducted to investigate the effects of higher body feed and the results are reported on page 133 of this report.

TABLE 35. RATE OF FILTER PRESSURE CHANGE DURING DE FILTRATION RUNS

Number of Runs	Average Filtration Rate (m/hr)	Filter Pressure Changes - psi/hr		
		Mean	Maximum	Minimum
5	2.4	7.9	23	2.0
5	4.2	12.3	20.0	5.0

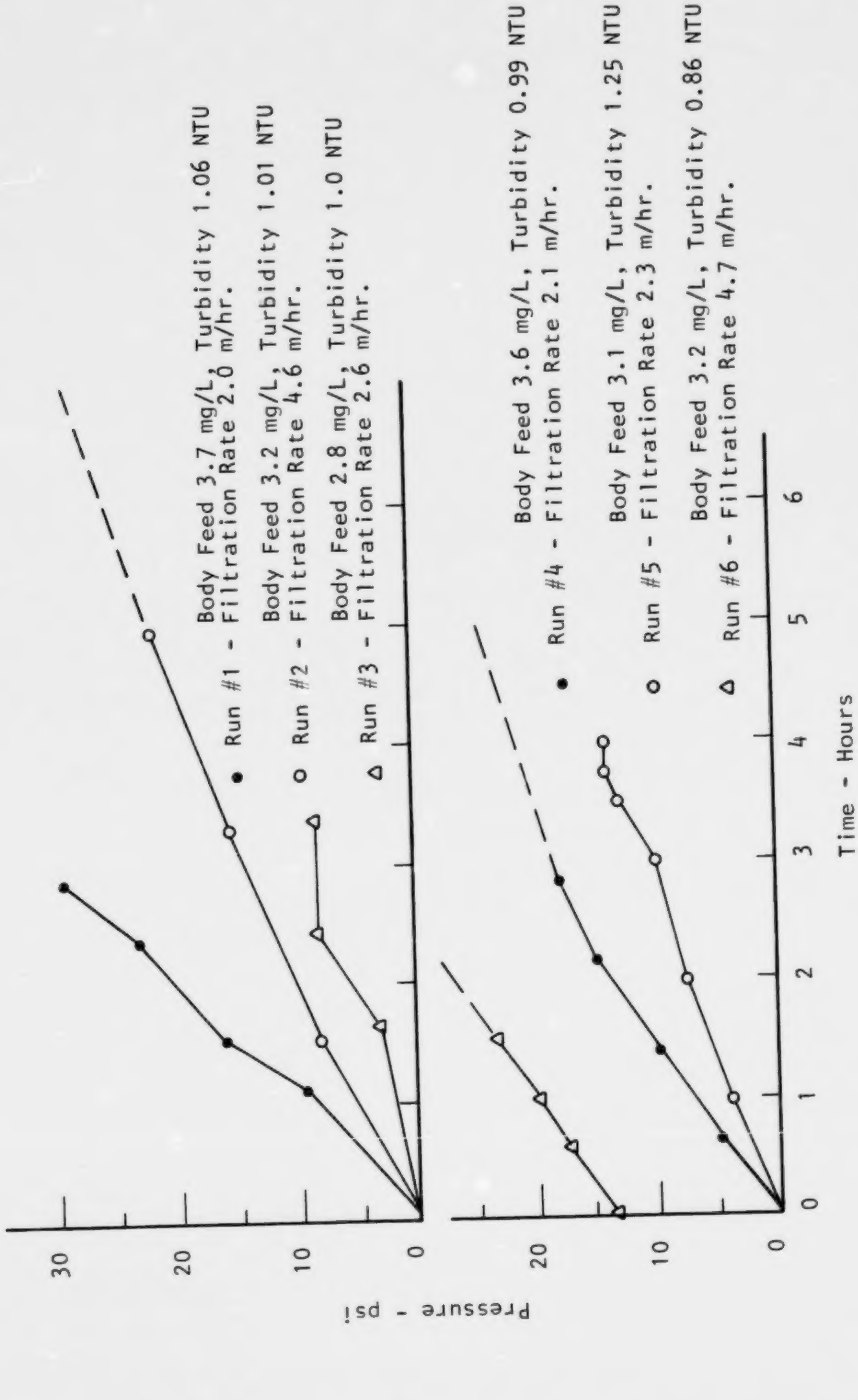


Fig. 31. DE Filtration, Filter Pressure vs Filter Run Time, Two Filtration Rates

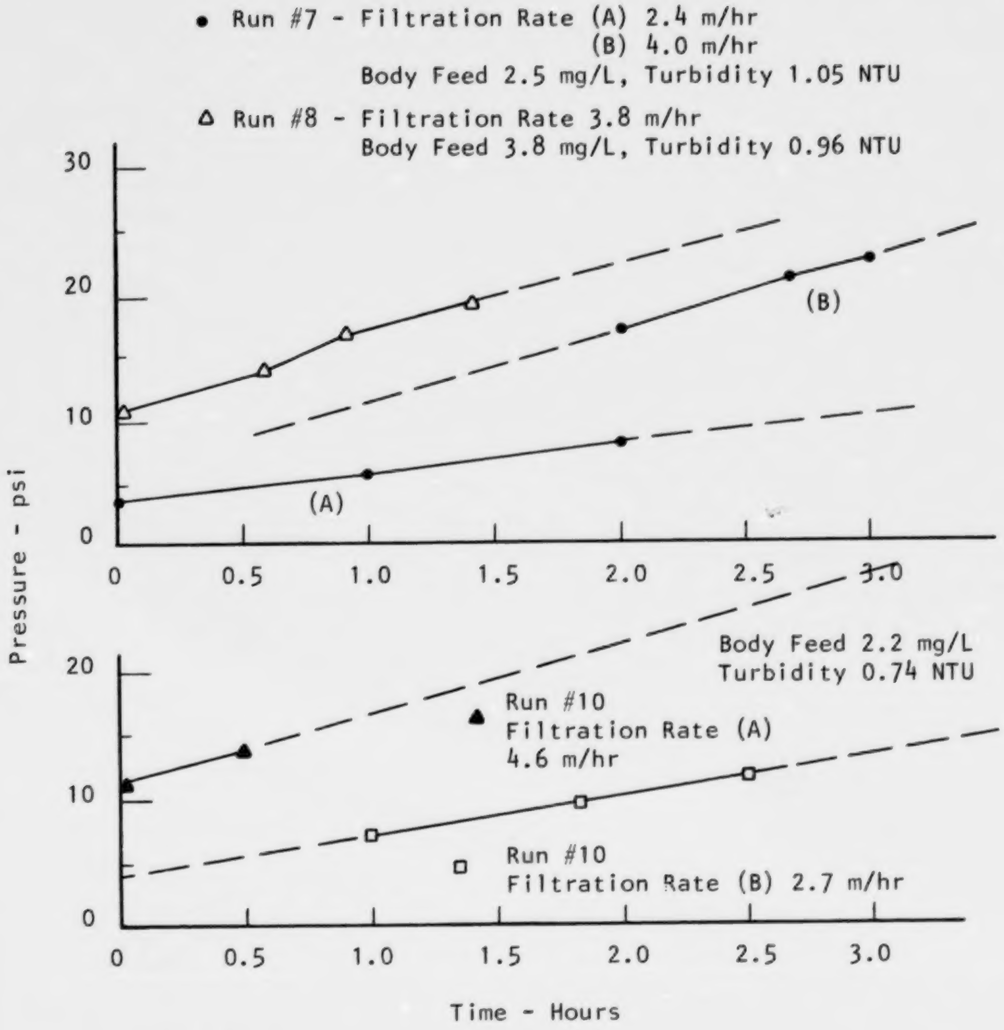


Fig. 32 DE Filtration, Filter Pressure vs Filter Run Time, Constant Body Feed

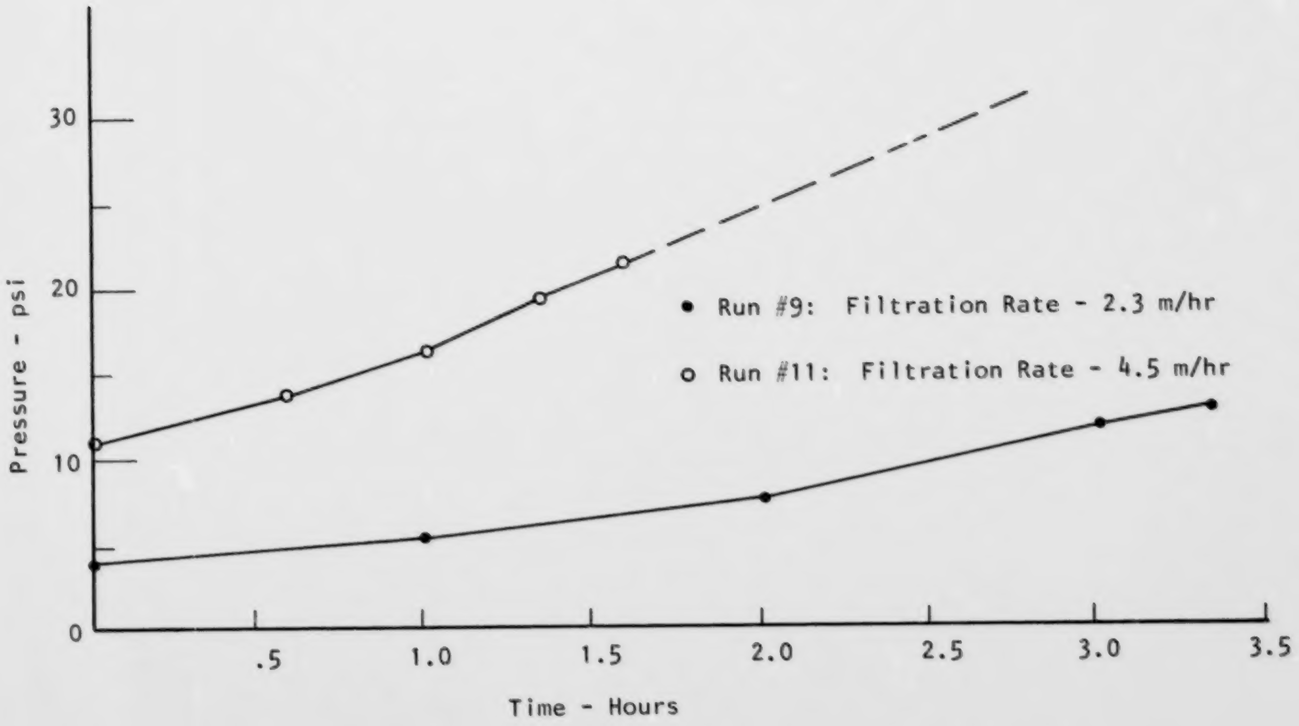


Fig. 33. DE Filtration, Filter Pressure vs Filter Run Time, Constant Body Feed Average Body Feed 3.3 mg/L, Turbidity 0.94 NTU

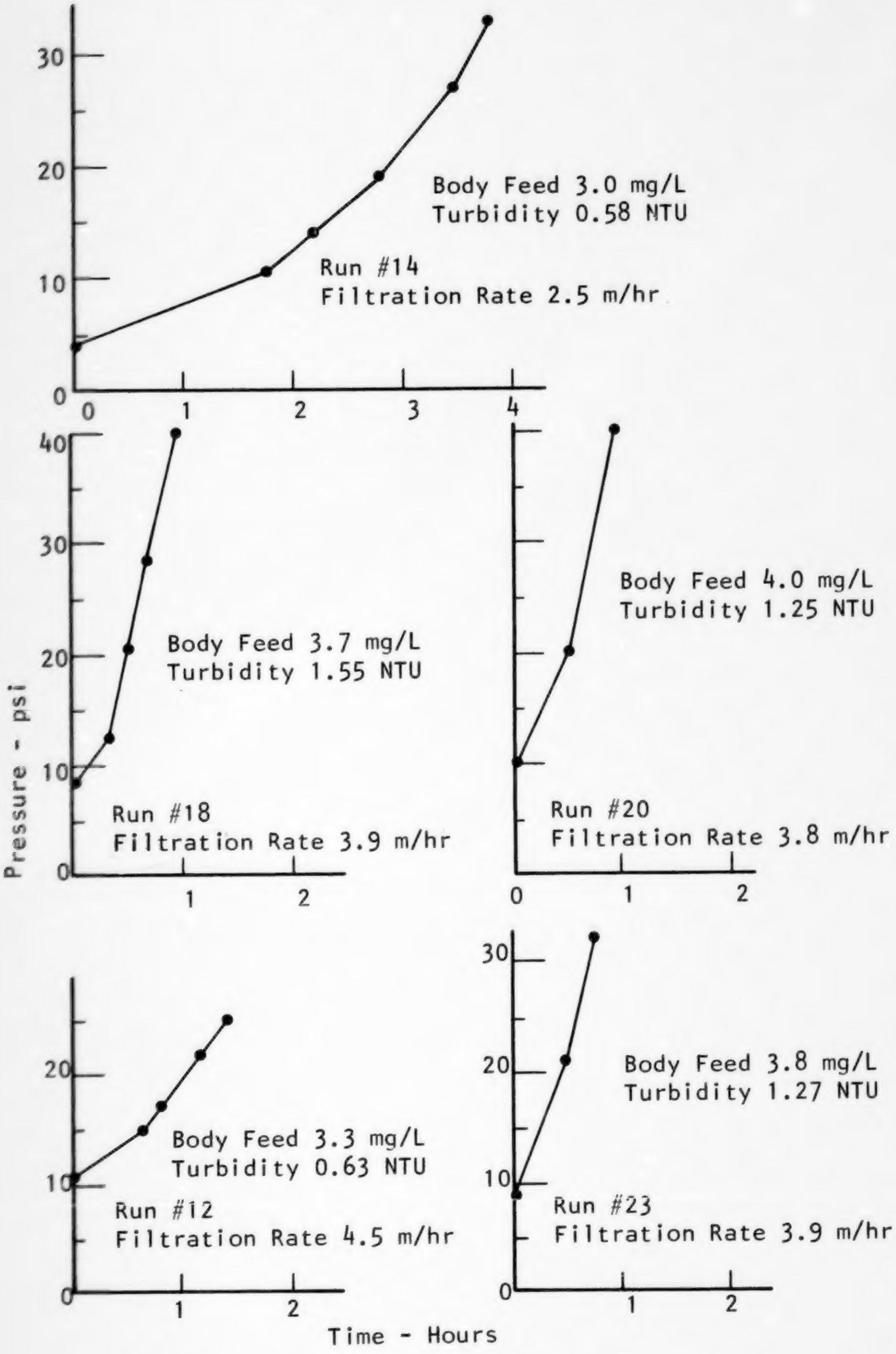


Fig. 34. DE Filtration, Filter Pressure vs Filter Run Time, Constant Body Feed

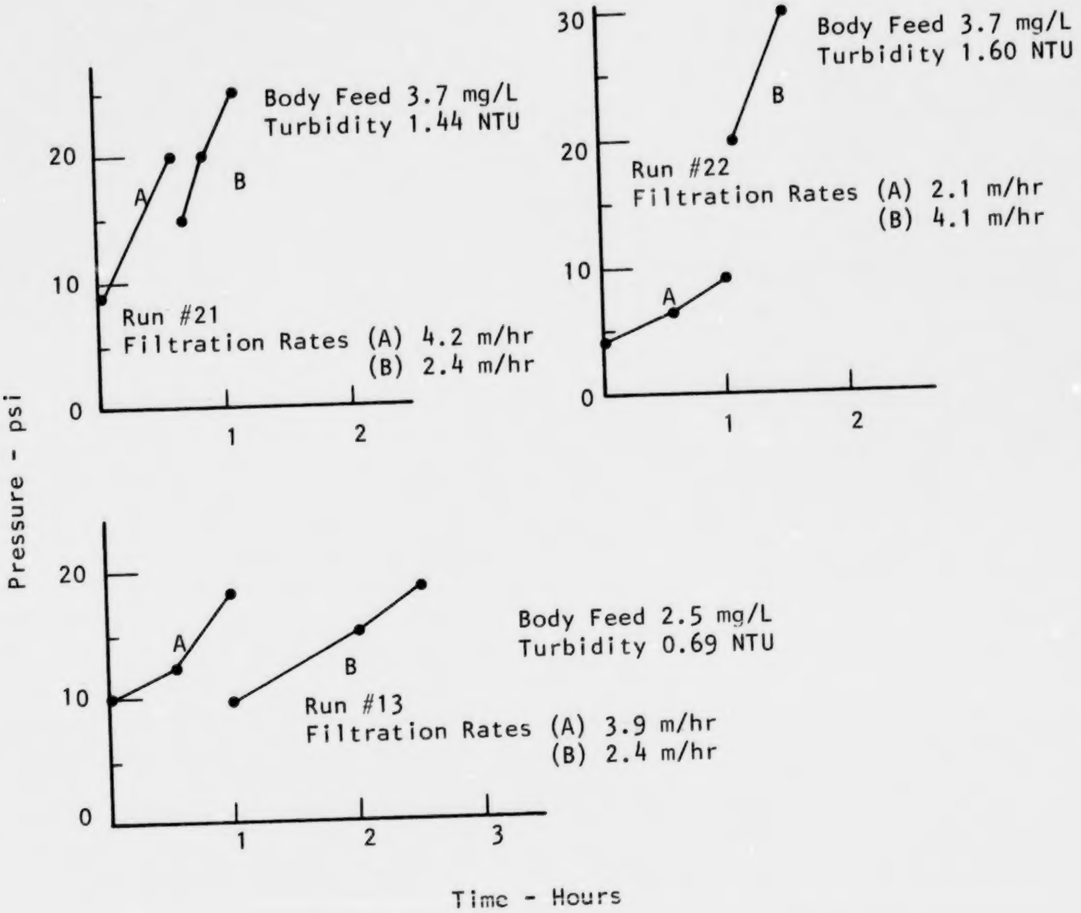


Fig. 35. DE Filtration, Filter Pressure vs Filter Run Time, Variation of Rate During Run, Constant Body Feed

Initial bacterial removal studies involved eleven runs at both low and high filtration rates using natural ambient background bacteria, total coliform and standard plate count organisms. The results of these studies are summarized in Table 36. During all of these runs the ambient bacterial concentrations were fairly low. As a result the total coliform reductions ranged from -60% to +95% and the standard plate count from -490% to 98%.

The bacterial reductions tended to be related to the raw water concentration. For the total coliform reductions when the raw water values were greater than 5/100 mL the percent reductions were more consistent with the raw water organisms. Below 5/100 mL the percent reduction tended to decrease to 0 or even negative values. Since the filter was not handled in a completely aseptic manner it would appear that 1 to 5 coliform per 100 mL could be part of the background contamination or low raw water bacterial concentrations could pass through. Above 5 total coliform per 100 mL the background contamination would be overshadowed by the raw water content and reductions were generally in the range of 80% or better.

For the standard plate count there appeared to be a similar relationship in that the percent bacterial reductions were below 80% when the raw water standard plate count concentration was below 30/mL. There were three negative values but these were found to be the result of water having soaked into the bottom of stored DE bags and this stimulated standard plate count bacterial growth in the DE, without the presence of coliform. From an experimental point of view this occurrence is not desirable but is reported here because it did not affect other parts of the determination and is indicative of what can happen in a small plant where storage may not always be the best and where many details can be overlooked by a part-time operator.

The average reductions for all runs during nonspiking conditions, where there were more than 5 total coliform per 100 mL applied or more than 30 standard plate count per mL applied, was 87.3% for total coliform and 88.8% for standard plate count. For total coliform 50% of the run values showed 92% reduction or greater and for the standard plate count 90% or better.

The low bacterial values in the effluent would not be a problem for an operating condition. Disinfection would be an integral part of any complete water treatment system and would kill the few remaining bacteria.

The nonspiked studies were broken down into two loading ranges under ambient bacterial conditions with two filtration runs involving change of filtration rate in the middle of the run. For the high filtration rate (average of 4.6 m/hr) the average percent reduction was 76.5% for total coliform (weighted by one extremely low result) and 86.8% (average 4.3 m/hr) for standard plate count. For the low rate filtration (average 2.3 m/hr) the average reduction was 92.0% for total coliform and (average 2.2 m/hr) 88.1% for standard plate count.

TABLE 36. BACTERIAL AND PARTICLE REDUCTION - NONSPIKE CONDITIONS CELITE 503

Run No.	Date	Water Temp. (°C)	Filt. Rate (m/hr)	Bacteria Total Coliform/100 mL Inf. Avg.	Eff. Avg.	% Red.
1	12/7/82	5	2.0	1	1	0.0
2	12/8/82	5	4.6	5	8	-60.0
3	12/8/82	5	2.6	5	3	40.0
4	12/9/82	5	2.1	96	5	94.8
5	4/13/83	2	2.3	35	4	88.6
6	4/14/83	3	4.7	38	2	94.7
7	4/15/83	4	2.4/4.0	5	1	80.0
8	4/15/83	4	3.8	7	1	85.7
9	4/18/83	4	2.3	9	1	88.9
10	4/19/83	3	4.6/2.7	1	1	0.0
11	4/20/83	3	4.5	12	5	58.3
16	5/19/83	10	2.4	70	5	92.9
17	6/16/83	21	2.1	8700	450	94.8

Run No.	Bacteria Standard Plate Count/mL Inf. Avg.	Eff. Avg.	% Red.	Inf. Avg.	Particles No./1 mL Eff. Avg.	% Red..
1	7	5	28.6	8110	2440	69.9
2	20	12	40.0	6860	7220	- 5.2
3	14	6	57.1	8090	4730	41.5
4	185	7	96.2	10690	2120	80.2
5	37	6	83.8	8720	1980	77.3
6	45	11	75.6	5970	2530	57.6
7	42	2	95.2	5750	2610	54.6
8	49	1	98.0	4170	2320	44.4
9	22	102	-363.6	4770	2730	42.8
10	13	72	-491.7	3780	1330	64.8
11	26	105	-303.8	1820	960	47.3
16	77	17	77.9	4690	3300	29.6
17	127	7	94.5	2430	5930	-144.0

The variable rate run was comparable to the other ambient condition runs or at least it did not show any degrading effect as the 95.2% reduction for the run was greater than the average for all runs. The total coliform reduction was 80% for the variable run and the average for the other ambient run conditions was 84% but the standard plate count reduction was 95.2% for the variable run and the average for the ambient conditions was 87.5, indicating no appreciable difference from the other runs.

The high rate runs appeared to produce slightly lower (average 76.5% for total coliform and 86.8% for standard plate count) reductions than the low rate runs (average 92.0% for total coliform and 88.1% for standard plate count). Although there may be a trend, these differences cannot be considered to be significant, because of the limited number of runs under each condition.

In general the rate of filtration did not demonstrate any significant effect on the percent reduction of total coliform or standard plate count organisms when raw water values were above 5/100 mL and 30/mL respectively.

Prechlorination or chlorination of the precoat and body feed tank would be needed to eliminate low levels of background bacteria where extensive amounts of manual handling and cleaning are involved, such as in a small water treatment plant. However, normal disinfection would eliminate any bacteria at the concentrations reported for these filter effluents.

Bacterial Spiking

Bacterial spiking studies were conducted with the DE filtration process by using wastewater treatment plant primary settling tank effluent as a source of bacteria. The use of bacterial spiking procedures ensured that there would be some evaluation and results using high bacterial concentrations in raw water and provided evaluation of the ability of the treatment process to respond to heavy pollution loads which can result from surface (also groundwater) contamination by sewage spills or facility breaks. Such spiking yields results under conditions which challenge the treatment process.

Twelve spiking studies were performed during runs 12 to 15 and 18 to 25. The results are summarized in Table 37. The average reduction for all runs during the spiking application was 97.6% for total coliform and 92.7% for the standard plate count. For total coliform 50% of the run values showed an average of 98% reduction or greater and the standard plate count was 93.5% reduction or greater. The table also shows a trend of somewhat higher percent reductions with higher raw water bacterial content although not a well defined relationship.

The spiking studies were broken down into two loading ranges of extremely high and moderate applied concentrations in addition to the high and low filtration rates. Three runs were conducted involving change of rate in the middle of a run. For the high rate (average 4.2 m/hr) and heavy spike run conditions the average percent reduction was 94.9% for total coliform and 92.0% for standard plate count. The high rate (3.8 m/hr) moderate spike runs the average percent reduction was 97.3% for total coliform and 93.2% for standard plate count. The low rate filtration (average 2.5 m/hr) and heavy spiking runs the average percent reduction was 99.1% for total coliform and 97.6% for standard plate count. The low rate (average 2.6 m/hr) moderate spike runs the average percent reduction was 98.5% for total coliform and 89.6% for standard plate count.

TABLE 37. DE FILTRATION - BACTERIA AND PARTICLE REDUCTION, SPIKING CONDITIONS CELITE 503®

				Bacteria								
				Total Coliform/100 mL			Stnd. Plate Count/mL			Particles No./1 mL		
Run No.	Date	Water Temp. (°C)	Filt. Rate (m/hr)	Applied Average	Eff. Avg.	% Red.	Applied Average	Eff. Avg.	% Red.	Inf. Avg.	Eff. Avg.	% Red.
12	5/17/83	11	4.5	$17x10^2$	107	93.7	$28x10^2$	39	98.6	6000	1960	67.3
13	5/17/83	11	3.9/2.4	$24x10^2$	61	97.5	$34x10^2$	7	99.8	4220	3190	24.4
14	5/18/83	10	2.5	$51x10^3$	275	99.5	$35x10^2$	25	99.3	4230	2700	36.2
15	5/19/83	10	2.6	$68x10^3$	955	98.6	$19x10^2$	78	95.9	4690	8130	-73.3
18	8/8/83	23	3.9	947	38	96.0	456	67	85.3	4330	3600	16.9
19	8/9/83	23	2.7	439	9	97.9	921	135	85.3	6330	5410	14.5
20	8/10/83	22	3.8	83	4	95.2	277	10	96.4	3840	3960	-3.1
21	8/10/83	22	4.2/2.4	115	2	98.3	233	26	88.8	6540	2910	55.5
22	8/10/83	22	2.1/4.1	80	2	97.5	272	28	89.7	4770	2140	55.1
23	8/11/83	21	3.9	940	7	99.3	449	45	90.0	3260	2890	11.3
24	8/11/83	21	2.3	146	1	99.3	471	40	91.5	4320	2370	45.1
25	8/12/83	19	2.7	380	7	98.2	890	70	92.1	3030	1630	46.2

The variable rate runs produced comparable results to the other spiking runs. The heavy spike run produced a reduction of 97.5% for total coliform and 99.8% for standard plate count as compared with the moderate spike run average reduction of 97.9% for total coliform and 89.3% for standard plate count.

The high rate runs appeared to produce slightly lower (average 96.1% for total coliform and 92.6% for standard plate count) reductions than the low rate runs (average 98.8% for total coliform and 93.6% for standard plate count) and the variable rate runs produced about the same (average 97.7% for total coliform and 94.6% for standard plate count) as the high rate and low rate average (average 97.5% for total coliform and 93.1% for standard plate count) reduction. These differences cannot be considered to be significant because of the limited number of runs under each condition studied.

In summary, these results indicate that at average rates of filtration, (2.5 - 4.0 m/hr, using Celite 503®, bacterial reductions of 98% or greater for total coliform and 94% or greater for standard plate count can be expected in 50% of the samples. The nonspike results indicated that in the range of 2.3 - 4.6 m/hr the total coliform could be expected to show 92% reductions or greater and standard plate count 90% or greater 50% of the time. The spiking study results tended to support the indication that the higher the bacterial loading the higher the percent reduction, as shown in Tables 36 and 37.

TURBIDITY REDUCTION

During all the DE filter runs, influent and effluent turbidity was recorded several times, depending on the length of the run. Reduction in turbidity did not appear to vary with filtration rate or type of DE used. The results of the observations are summarized in Table 38. This table shows that the raw water turbidities were low (less than 7 NTU). The natural water at times did have values as high as 15 to 59 but only in short duration spikes and only 2 or 3 times during the whole study, none during the DE studies. The average reduction of 71% provided an average water turbidity in the effluent of 0.5 NTU which would meet current standards. Five runs out of 38 had turbidity values higher than 1.0 NTU in the effluent, one at the high filtration rate and four at the low filtration rate.

TABLE 38. DE STUDIES - TURBIDITY DATA, AVERAGE/RUN (38 RUNS)

	Mean	Maximum	Minimum	Standard Deviation
Influent (NTU)	1.85	6.58	0.58	1.33
Effluent (NTU)	0.51	1.48	0.16	0.36
Percent Reduction	71.4	83.2	52.5	----

These turbidity results may not provide the full indication of particle treatment or removal. The dark brown to black appearance of the DE cake at the end of all runs indicated that there was a large amount of material in the water which was being removed by the filter. Much of the material on the filter cake appeared to be similar to the slimes and organic deposits found in the monitoring turbidimeter tubes and units. Factors other than raw water turbidity affected the rate of pressure build-up during filtration. At times there were rapid rates of build-up as shown in Figure 34 and at other times less rapid and more linear relationships developed as shown in Figures 31 through 33 for relatively the same turbidities, filtration rates, and body feed values. Turbidity did not appear to be a suitable criteria to use in regulating body feed for this water. Turbidity might serve as a starting guide but appearance of the filter cake surface might be a better criteria for final operation control. Other grades of DE might have worked better for this particular water.

Giardia Removal

Limited DE filtration tests were conducted on the filter's ability to remove *Giardia* cysts. Previous studies have shown excellent removal of cysts by DE and also there was a need to conserve the cyst supply for other studies on the slow sand filter.

The *Giardia* cyst spike study was conducted using Celite 503®, filtration rate 3.8 m/hr, temperature 23°C and the spike consisted of 8×10^6 cysts applied in 5 min. The number of cysts supplied gave an average concentration of 2,484 cysts/L but as an instantaneous spike the effective concentration would have been about 10 times this value or 2.5×10^4 cysts/L. Sampling of 5.3% of the effluent indicated that some cysts did pass through the filter (48 cysts recovered on sampling filter) and appeared in the effluent but the percent removal was 99.97, an excellent removal considering the massive load situation. This result is consistent with earlier results obtained by USEPA, the University of Washington and Colorado State University. This would have given an average concentration of one cyst/1.54 L in the effluent under massive spike load conditions.

In contrast with the slow sand filter, temperature should have little effect on cyst removal by DE filtration even though the reported removal was for warm water conditions.

Particle Reduction

The reduction of particles in the 7 to 12 um range was evaluated in the DE studies (runs 1 to 25) for two rates of filtration and 3 mg/L/NTU of body feed (Celite 503®). Percent reduction tended to be erratic and variable and ranged from a low of -144 to 80.2% for all runs with an average of 30.3%. The average values of all runs are shown in Tables 36 and 37 for nonspiking and spiking conditions. There was no apparent difference in removal between the average filtration rates of 2.4 m/hr and 4.4 m/hr. The average percent removal for the 2.4 m/hr runs was 22% and for the 4.4 m/hr was 30%. Reductions of 43% or better were observed in 50% of all the runs studied. For the 2.4 m/hr filter runs, 50% of all the runs had 42.2% reduction or better and for the 4.4 m/hr filter runs, 50% had particle removals of 34.7% or better. These values do not indicate a real significant difference in the results. It appears that the particle reduction results do not relate to the *Giardia* cyst reductions which were 99.99%. From these data it appears that particle reductions do not give a good means of evaluating the removal of *Giardia* cysts, at least for water of these characteristics.

Slime growths again may have accounted for some of the low results. At times it was reported that slime material tended to clog the particle counter and thus would undoubtedly have affected readings. In these studies the particle readings proved to be extremely unpredictable and did not appear to have any direct relationship with turbidity reduction or *Giardia* cyst removal.

Trihalomethane Precursor Reduction

The results of the precursor reduction were reported with the slow sand filter data on page 114. Figure 29 shows the results of the TTHM formation in the DE effluent for cold water conditions ((G) 12/82 at a filtration rate of 2.6 m/hr, temperature 5°C) and for warm water ((H) 6/83 at a filtration rate of 2.2 m/hr, temperature 20°C). Comparing these results with the raw water characteristics, it appears that there was very little difference and thus little precursor reduction through the filtration process as was also shown in the slow sand filter effluent figure. Figure 30 shows the composite of the results for all values and waters. The DE may have been less effective than the slow sand filter in removing precursors. However, the variation is only about ± 10% and this is within the variation of the data. Therefore, very little effect on the precursor reduction was observed from either system of filtration.

Under different water conditions the results could be different from those observed. It would appear that the precursor materials were primarily in soluble form and thus would not be removed by conventional DE filtration. If precursors were in colloidal or particulate form, greater removal could be expected in DE filtration and probably also in the slow sand filter treatment approach.

Pressure-Time-Body Feed Relationships

DE studies were conducted using various body feed concentrations (average 4.3, 8.1, 18.7, 36.1 mg/L) and two filtration rates (average 2.8 and 4.5 m/hr). Typical results of these studies are summarized in Table 39 and in Figures 36 and 37 showing the effect of the various body feed concentrations on length of run and change in pressure build-up. At an average filtration rate of 2.8 m/hr (Table 39 and Figure 36) the filtration operation time tended to increase with increasing body feed for the 2 lowest feeds, but the next 2 higher feed concentrations produced decreased filter run times. Increasing filter run time with increasing body feed is normally expected under such conditions. At the higher filtration rate shown in Table 39 and Figure 37 (average 4.5 m/hr) the filter run time responded in a similar manner with increases of body feed. Also increased body feed did not change the pressure run time relationship from exponential (Figures 36 and 37) to linear as would be expected by DE filtration theory.[31]

In order to compare the pressure relationships for the various filtration rates the run length potential was evaluated on the basis of the time required to reach a change in pressure (final pressure reading minus initial pressure reading) of 20 psi. The results of this evaluation are shown in Table 39 in which the average body feed concentration is related to the average time for the change in pressure to reach the value of 20 psi for all runs. These results show that as the filtration rate increased, the time of filtration decreased and in direct proportion to the change. Thus, doubling of filtration rate produced a run time one-half as long.

These responses appeared to be affected by the characteristics of this raw water, which have been noted at other times. There was a considerable amount of slime, organic material and at times iron present in the raw water. All of these parameters could not be monitored for this project and also they appeared to be variable by season. An extensive amount of additional work would have had to be performed to have arrived, if it were possible, at a satisfactory operating mix of body feed and DE grade.

Effects of DE Grades

One other DE grade, Celite 512 (finer than Celite 503) was used in two runs to study body feed concentration effects on the rate of pressure build-up. Figure 38 shows that at a filtration rate of 2.6 m/hr the 27.6 mg/L/ body feed produced much longer filter runs than the 9.2 mg/L at the same filtration rate and even longer than the Celite 503. These results

TABLE 39. DE FILTRATION - VARIABLE BODY FEEDS AND TWO FILTRATION RATES

No. of Runs	Filtration Rate m/hr	Body Feed mg/L Average	Maximum	Minimum	Turbidity NTU Average	Maximum	Minimum	Time to Reach 20 psi hr Average	Maximum	Minimum
2	2.6	4.8	5.9	3.7	5.2	6.6	3.7	1.5	1.9	1.1
1	3.5	9.0	----	----	3.0	---	---	1.8	---	---
1	2.6	19.1	----	----	3.1	---	---	1.7	---	---
3	2.5	25.4	38.9	32.4	3.8	4.4	3.3	1.1	1.3	0.9
1	4.7	3.7	----	----	1.1	---	---	0.7	---	---
1	4.4	7.2	----	----	2.6	---	---	1.4	---	---
1	4.5	18.2	----	----	3.0	---	---	0.8	---	---
1	4.3	36.7	----	----	4.0	---	---	0.6	---	---

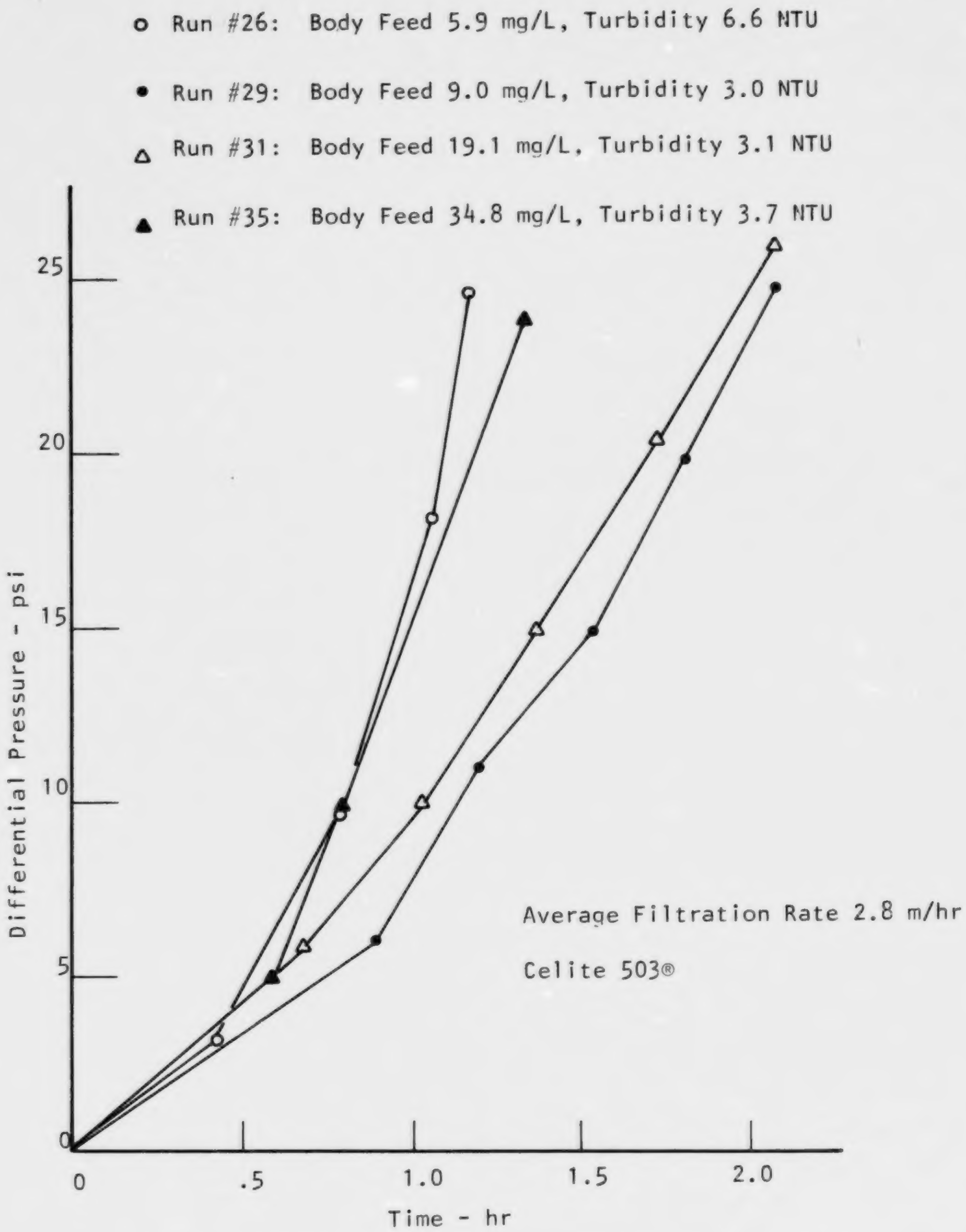


Fig. 36. DE Filtration, Filter Pressure Change From Start of Run vs Filter Run Time, Four Body Feeds

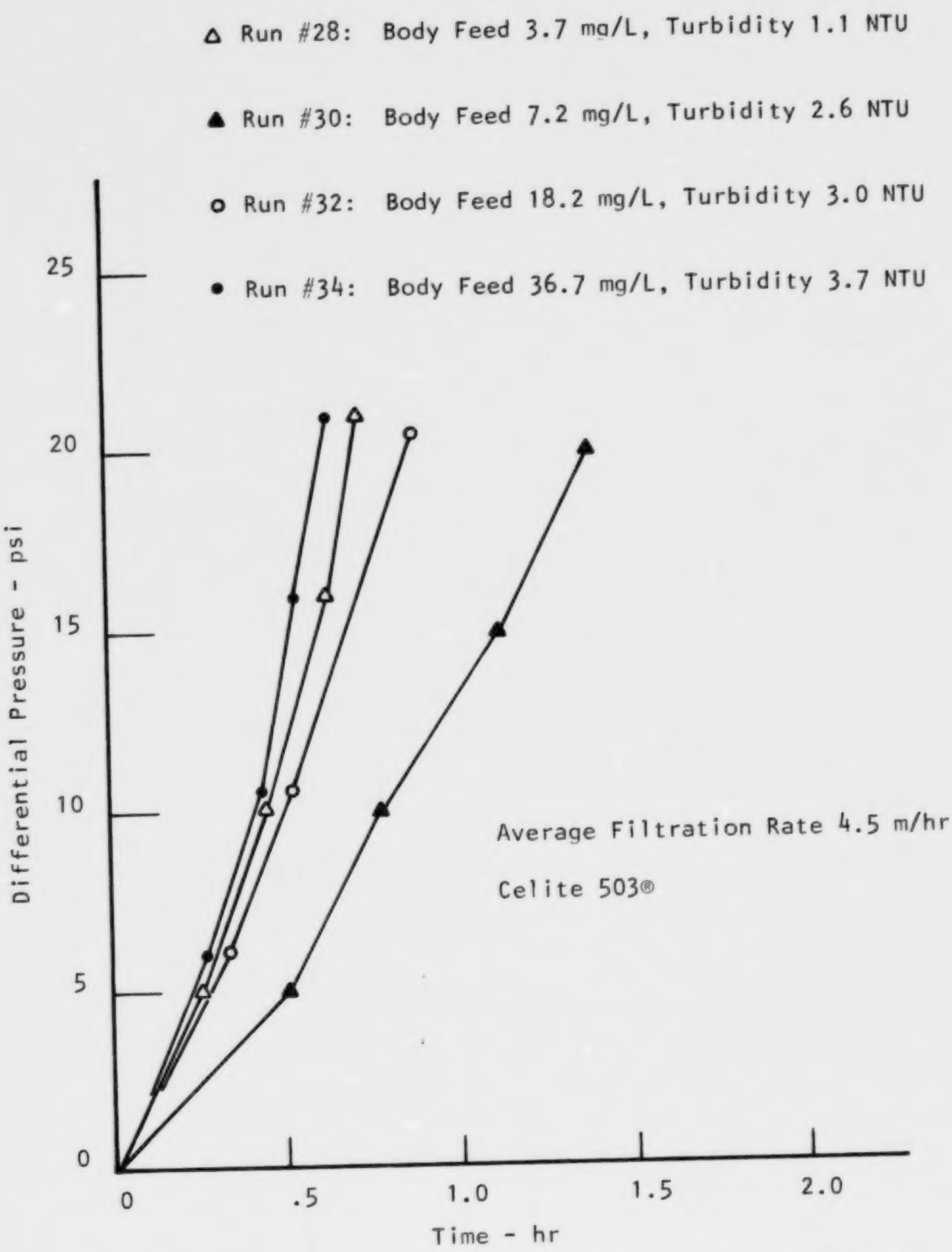


Fig. 37. DE Filtration, Filter Pressure Change From Start of Run vs Filter Run Time, Four Body Feeds

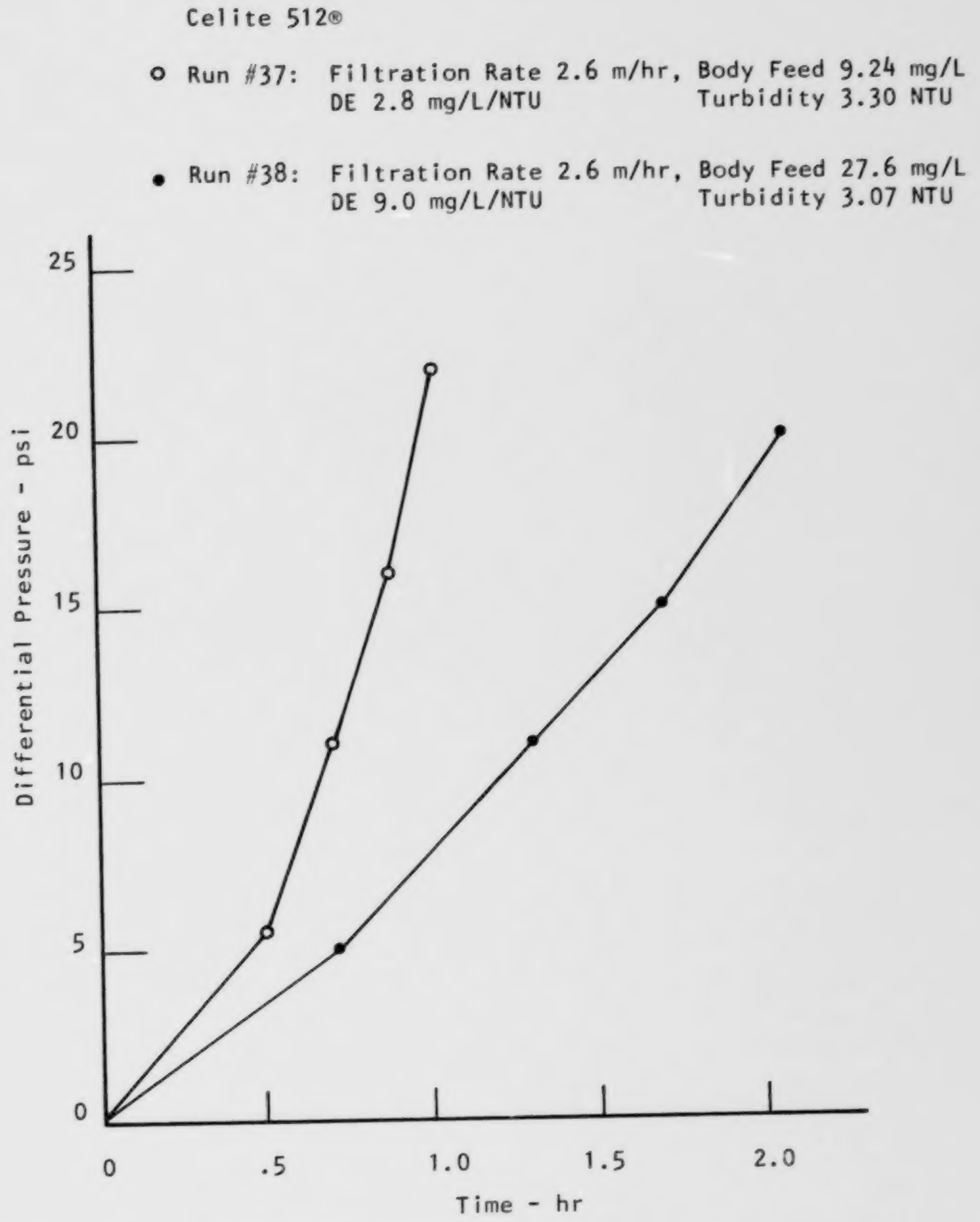


Fig. 38. DE Filtration, Filter Pressure Change, From Start of Run vs Filter Run Time, Two Body Feed Values

indicate that the finer DE grade(s) might be more advantageous for treating this particular water. Similar range studies would be needed for completion of treatment potential to ensure the most advantageous body feed and filtration rate for treating this water with its low turbidity, from time to time fairly high bacterial concentrations, some iron, and heavy organic and slime growth characteristics.

SECTION VII

OPERATION AND COST ANALYSIS

SLOW SAND FILTER

The slow sand filter surface was cleaned five times during the course of the study. Since the filter had been used for a period of time and then allowed to dry for several years, the filter was operated without recording data for several months to rejuvenate the filter flora and fauna and ensure that the filter was operating satisfactorily. Before data were collected the wet filter was cleaned at the start of the study and also at the very end of the study. The filter was also cleaned three times during the course of the study to either rejuvenate the filter because of excessive head loss (one run), to ensure that the filter was clean and would not have to be cleaned during a particular run (one run), and one cleaning was performed in order to obtain more cleaning data. The objective in obtaining cleaning data was to evaluate this operational requirement for small filters.

Cleaning involved draining the water from the slow sand filter to at least four or five in. below the sand surface before cleaning could commence. This draining process required a lead time of about 18 hours, and thus the drawdown was usually started about 2 to 4 o'clock in the afternoon preceding the day of the cleaning. This made it possible to start cleaning about 8 to 10 o'clock in the morning.

The cleaning time appeared to be primarily related to the thickness of the schmutzdecke and dirty sand. The thicker the biologic surface growth the longer it would tend to take to clean the surface. However, it did not appear that a direct relationship could be related to the length of filter run and the amount of build-up. Table 40 summarizes the effort and conditions under which the slow sand filter was cleaned. From this information an equation was developed which represents the number of person hours which could be expected to be expended on cleaning a slow sand filter, in the range of 0.28 to 1.7 cubic meters (10-60 cubic ft) of sand removed.

$y = 1.6 + 3.5\ x$
y = person hours to clean filter
x = volume of sand removed (m^3)

The range of y was $\pm\ 1.0\ y$ since there was a considerable amount of variation in any one determination. ($y = 1.6 + 0.1\ x$ if x is expressed in cubic feet).

TABLE 40. SLOW SAND FILTER CLEANING
(Filter Size 37.2 m^2) (400 ft^2)

Date	Duration of Cleaning hr	Total Person-Hours	Sand Removal				Person-Hours per 100 ft^3	Head Loss cm	Actual Filter Run days	Sand
			Depth (in)	cm	Volume (ft^3)	m^3				
5/10/82	3	5	(0.47)	1.2	(45)	1.27	11	---	---	Dry
1/24/83	2	8	(0.69)	1.75	(58)	1.64	14	168	259	Wet
7/5/83	2	4	(0.20)	0.5	(17)	0.48	24	11	163	Wet
10/20/83	3.5	3.5	(0.16)	0.4	(13)	0.37	27	30	107	Moist
6/12/84	1.5	3	(0.30)	0.75	(25)	0.71	12	34	214	Dry
Mean	---	4.7	(0.36)	0.9	(32)	0.89	18	61	186	---

The cleaning of slow sand filters for small water systems is affected by many factors including construction and temperature conditions. The slow sand filter studied in this project was covered with a concrete roof and access was through a hatchway and a wall hung ladder. The concrete roof was only about 5 ft above the sand surface and thus only a short person could stand erect and work on the sand. All of the sand had to be removed by flat shovels and brought to the hatchway where it could be thrown out onto the ground surface. The data reported in this study did not include any sand removal from the site, sand cleaning or storage.

Air temperature would tend to affect the time it takes to clean the filters. In the middle of the summer the warm temperatures tended to slow the cleaning process because of personnel heat exhaustion and in the extreme of winter the cleaning process tended to be slower because of gaining access to the filters and because of some ice accumulation on the surface of the water which then tended to collapse and collect on the surface of the sand. Spring and fall tended to be the easiest times to clean the filter.

The second cleaning on January 24, 1983, was performed after the longest filter run, at head loss of 168 cm. This long run had built up an extremely heavy surface biological layer. After draining the water from the filter about 5 in. of water remained on the surface even though the water had drained out from underneath the surface layer. Part of the heavy build-up at this cleaning and for other cleaning situations appeared to be the result of iron precipitation. The raw water at times contained a fairly high iron concentration as shown in Table 1 on page 12 and Table 25, page 122, ranging from .02 to 1.5 mg/L. The brown-colored accumulation on the surface of the sand was analyzed and found to contain large quantities of iron, particularly from the long run, high head loss run.

Figure 25, page 112, shows the observed relationship of head loss with filter run at the rate of 0.08 m/hr (2 mgad). As can be seen from this curve the head loss tended to vary extensively with filter run. The filter run to a head loss of 168 cm was the one in which large quantities of iron were identified. Further research would have to be performed to specifically relate what might cause the almost exponential increase but it would appear that iron accumulation may have contributed to this sudden change from a rather flat head loss relationship to a rather accelerated head build-up. Other runs did not show this sudden change, although if time had permitted longer run periods could have been experimented with and the same relationship might have been observed. However, if iron were the major contributing factor extensive studies would have to be conducted because the iron content might vary with season, temperature, and other parameters.

Slower or higher rates of filtration would undoubtedly produce some effect on cleaning time but it would not be expected to be a greater variable than observed under the constant 0.08 meter per hour filtration rate. The primary influence would be shorter filter runs although more rapid filtration rates would probably contribute to increased penetration of the organic material in the schmutzdecke surface and thus more sand might have to be removed. Higher rate filtration could not be studied because of the uncertainty that there would be adequate quantities of water at all times for rates of filtration higher than the 0.08m/hr studied. Also by concentrating on one filtration rate more complete data was obtained for the various parameters being studied.

GENERAL OPERATIONS

The operator maintained a daily operation log book, from May 11, 1982 to April 29, 1984. In the log book he recorded all of the daily activities involved in operating the plant and conducting the research study. Included in this record was the information related to activities, readings, and times required to perform all activities at the plant including bacteria and turbidity sampling, maintaining the automatic turbidimeter equipment and records, adjusting of flow rates, and improving the equipment. The values reported did not include grounds maintenance, painting or any physical improvements.

For the 700 reported days the average operation time was about 1.5 hr About 5% of the time the operation was 1.25 hr or less and about 10% of the time 2.0 hr or more. Most of this operation time was involved in bacteria and turbidity sampling and data recording. Table 41 summarizes the observed operation testing information for several combinations of operation activities. The average operation time of 1.5 hr was mostly the result of turbidity and turbidity/bacteria sampling and testing as shown by the mean value in Table 41.

TABLE 41. SLOW SAND FILTER PLANT OPERATION - TURBIDITY, BACTERIA AND CHLORINATION

	Turbidity* and Temperature	Bacteria* Turbidity and Temperature	Chlorine**	Chlorine Preparation
Number Observations	168	46	103	53
Mean (hr)	1.46	1.54	0.38	0.20
Maximum (hr)	2.50	2.00	1.72	0.75
Minimum (hr)	0.75	0.58	0.17	0.08
Standard Deviation (hr)	0.30	0.34	0.21	0.13
Unit Analysis (hr)	0.35	0.37	0.21	-

*Influent and Effluent Samples
**Effluent Sample Only

Operation time results are very variable in any particular situation for many reasons including the human element factor. This element involves rapidity of motion, care, attention to safety, and dexterity. In addition, factors such as power failures, weather conditions, and facility orientation influence such results.

For this project the operator was very conscientious and careful, particularly with respect to test results because of his awareness that the research project would require good values. Frequently the operator sampled and tested for turbidity three, four or five times in order to ensure satisfactory values when he was encountering problems.

To evaluate the distribution of the observed operation times a unit activity study was conducted. This study involved recording the time required to perform each major step of the turbidity, temperature, bacteria, and chlorine testing process. These values are for influent and effluent for temperature, turbidity, and bacteria samples and for chlorine residual in the effluent only. The bacteria time values were only for collecting bacteria samples, recording the data, and storing the samples in a refrigerator.

The unit activity analysis involved turning on the turbidimeter on arrival at the plant laboratory, taking sample containers to plant (2 min), read and record influent and effluent temperatures and turbidity (1 min), collect influent and effluent samples for bacteria (3 min) and for turbidity (3 min), collect effluent sample for chlorine test, take samples to the laboratory (2 min). In the laboratory record bacteria sample data (2 min), complete bacteria sample cards and place samples in refrigerator (3 min), test for chlorine (4 min), record chlorine (1 min), clean-up chlorine (1 min), run turbidity (2 min), record turbidity and temperatures (2 min), and clean-up turbidity (2 min). The total time involved including bacterial sampling was 30 min and if bacterial sampling is excluded (not performed daily in small plants) the time was 22 min.

It should be noted that these values do not allow for any problems, mistakes, errors, bad weather, and it assumes that the turbidimeter has been turned on and warmed up. Any combination of problems can and do usually occur in actual operation. The analysis does show that the fastest possible time to accomplish the complete minimum testing process for a surface supply being treated by slow sand filtration is 30 min with bacteria sampling and 22 min without. It would not be possible to average less than two times this value for 365 days a year operation in all types of weather and conditions. Therefore a minimum of 45 min to 1 hour would be realistic for performing the complete sampling and testing described.

The values from this unit analysis were used to develop base reference figures for other combinations of operation testing. The minimum daily operation for good practice would involve turbidity, temperature, chlorine residual, flow rate, and head loss. This routine operation activity would require a minimum of 26 min including 4 min for reading and recording head loss and filter flow rate (from a water or rate meter). On bacteria sampling days, the time would increase to a minimum of 34 min.

In Table 41 there is also an evaluation of the time required to prepare the chlorine solution for the chlorinator from hypochlorite powder. These results are subject to much interpretation because of the many variables that can be involved. These observed values were even affected by the methods and particularly the improvement of methods of preparing the solution which the operator developed by experience. At first the operator was mixing powder in the chlorination tank and this caused many operational problems and an extensive amount of stirring each day to ensure that proper mixing and that solution was accomplished. As is common with hypochlorite powders, a deposit persisted in the bottom of the hypochlorite solution tank and thus the operator reverted to the approach of mixing a container of water and hypochlorite powder several days in advance, or daily when needed, so that a clear supernatant could be poured off the powder mixture to provide the chlorine solution and thus reduce the problems and time required to prepare chlorine solutions. At first the chlorine solution preparation time was on the order of 30 to 45 min from one to three times a week. This time was reduced to about 5 min a day when making smaller decantation batches and adding the supernatant from the previous day to the chlorination tank. The mean value of 0.2 hr is a reasonable representation of the amount of time required for an experienced operator where the method of handling the chlorine powder and solutions has been worked out both in procedure and routine.

In comparing the minimum time values developed by the unit analysis with the mean values in Table 41, it is evident that the mean results are in an expected range for the careful and deliberate operating method used in this project. Nonresearch oriented operation would be expected to be somewhat less and thus the operational sampling and testing for bacteria, temperature, turbidity, and chlorine residual would be expected to require in the range of 0.75 to 1.5 hr per day. Chlorine testing alone could be expected to be about the mean value observed or about 0.4 hr, probably 0.3 to 0.5 hr. These times do not allow for standardization of equipment, equipment maintenance or any other special activity which would be associated with ultra careful work or special problem situations.

CONSTRUCTION COSTS

The dual filter (37.2 m^2, 400 ft^2 each) treatment plant with reservoirs and hypochlorination equipment cost \$113,000 to construct in 1975. The construction was by contract under the supervision of the Vermont Highway Department. Current cost to replace the same type of facility would be about \$226,000 based on an average ENR construction cost index ratio for the area of about 2 (200%) in comparing 1984 to 1975.

If a community were paying the full construction, operation and maintenance costs of the treatment plant at current operating and construction costs the water would cost about $9.20 per 1000 gal. This is based on a production cost estimate with interest at 10%, life at 20 years (240 months) and calculated on a monthly payment basis.

$$\text{Payment} = (P \times i) + (1 - (1 + (1+i)^{n}))$$

On this basis the monthly production costs would be:

Monthly payment -	$2,181
Chemicals -	5
Electricity -	20
Maintenance -	100
Operator - 1.1 hrs/day @ 7.50/hr -	251
	$2,560

The plant operating at the full design filtration rate of 0.08 m/hr would produce 18,000 gpd. This would provide 558,000 gal per month or a theoretical cost of $4.60 per 1000 gal. The current rate of use of the filter is at about 9,000 gpd or half the rated capacity and thus the theoretical cost would be $9.20 per 1000 gal. Since the system is serving 170 people the full cost for water is about $15.05 per person per month or approximately $45.15 per connection per month ($542 per year) if the plant cost was the current adjusted estimated capital cost of $226,000. This a fairly high cost per service, but frequently for very small systems construction cost subsidies and support grants reduce this to more conventional cost levels. The current users are not paying anywhere near these amounts.

DIATOMACEOUS EARTH FILTER

A small pressure DE filter similar to the 10 ft.^{2} (0.93 m^2) septum filter could produce almost as much water per day as the 400 ft.^{2} (37.2 m^2) slow sand filter used for the research. Clean-up and next run preparation and precoat times would reduce the theoretical capacity at any given filtration rate. The 10 ft.^{2} (0.93 m^2) unit could meet the 9,000-12,000 gpd needs of the community even with clean-up, preparation, and precoat time.

The DE filtration operation times, under research conditions, were extremely variable for this study. Many of the filter runs were very short and in many of the filter runs optimum body feed could not be obtained, even with extremely high applications of body feed. The best filtration duration times using Celite 503® , extrapolated to 60 psi cut-off pressure, was an average of 15 hr with a maximum of 25 hr and a minimum of 6 hr. To produce 9,000 gal per day from a 10^2 unit would require an operation of 16 hours. Therefore, for practical considerations, a 20 ft^2 unit would be needed to operate 8 hours a day and and a 40 ft^2 unit would be required to match the production capability of the slow sand filter at design capacity.

This research study did not provide sufficient DE operation data to extrapolate DE costs in a meaningful manner. There were too many operation variables in the research mode to be able to develop operational information which would be comparable to real functioning water supply situations. The normal operation data for the DE filtration work was not comparable to that obtained for the slow sand filter.

Some DE and slow sand filter operation comparisons can be deduced from the research studies. Costs for small systems will always be higher per 1000 gal of treated water than for larger systems. The DE process is highly labor, materials, and energy intensive, but is very flexible in that if water is not needed the labor, electricity and DE costs are reduced. Slow sand filtration is very capital intensive and if the plant is operating at reduced capacity, there is very little decrease in the total cost of production.

From a cost point of view slow sand filtration and DE filtration would probably be comparable for small water system use depending on conditions. The DE unit would definitely have advantages if at times there were high demands which would not be met by normal storage provisions. Operation of the DE unit at longer than normal operation on a daily basis would produce larger quantities than design capacity on an eight-hour day operation. For a slow sand filter the peak demands would have to be considered in the initial design and thus the capital cost built into the plant would make the slow sand filter cost less favorable. Additional storage could compensate for some of the peak demand requirements, but this would again introduce fixed capital cost.

The production cost values for slow sand filtration and probably DE filtration for very small systems are high as compared to some small systems recently constructed in the area. A small water treatment facility recently built in the area providing water for 2,500 people operating at about one-third capacity is producing water at about 0.45 dollars per 1000 gal and at full capacity is expected to produce water at about 0.40 dollars per 1000 gal. This demonstrates that the cost of providing municipal water to the very small community increases tremendously per user as the size decreases from 2,000 to 3,000 people to 200 to 300 or fewer people.

It may appear that this evaluation provides an unfavorable comparison for the small water system when considering slow sand filtration (or even DE treatment) costs. However, the home well water system costs about \$600-\$700 per year unless a questionable spring or shallow well can be developed. A home of three people will use about 180 gal per day at a cost of about \$10.70 per 1,000 gal. Therefore, a cost of \$5 per 1,000 gal is not unreasonable for good water quality as compared with the home system. If insurance and distribution main costs are included with the production costs, the total cost would be about comparable to the good, well built, and properly protected home water system. Public water supply construction cost assistance tends to keep the small municipal water system costs competitive with and often less than the home water system, at least in the area where this research was conducted.

SECTION VIII

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SECTION IX

GLOSSARY

AC	asbestos cement
°C	degree Celsius
cm	centimeter
CT	concentration multiplied by contact time
DE	diatomaceous earth
DO	dissolved oxygen
e.s.	effective size
ft	feet
FTU	formazin turbidity unit
g	gram, gravity
gpm	gallons per minute
gpm/ft^2	gallons per minute per square foot
hr	hour
I.D.	inside diameter
in.	inch
L	liter
M	molar concentration
MCL	maximum contaminant level
m	meter
m/hr	meter per hour

mL	milliliter
mm	millimeter
µm	micrometer
mg	milligram
mg/L	milligram per liter
µg/L	microgram per liter
mgad	million gallons per acre per day
mgd	million gallons per day
mi	mile
mi^2	square miles
min	minute
NTU	nephelometric turbidity unit
pH	negative log of hydrogen ion concentration
PVC	polyvinyl chloride
RPM	revolutions per minute
sec	second
SPC	standard plate count
TDS	total dissolved solids
t	time
TC	total coliform
THM	trihalomethane
TTHM	total trihalomethane
u.c.	uniformity coefficient
vs	versus

APPENDIX A. SLOW SAND FILTER FLOW CHECKS

Date	Wt (lbs)	Time (sec)	Minimum Flow Rate gpm	Maximum Flow Rate gpm	Remarks
5/27/82	28.5	18	11.4	12.9	
6/10/82	28.5	13	15.8	17.3	High
6/10/82	28.5	15	13.7	15.2	Adjusted
6/24/82	28.5	14	14.7	16.2	High
6/24/82	28.5	15.5	13.2	14.7	Adjusted
7/1/82	28.5	16	12.8	14.3	
7/8/82	25.5	15	12.2	13.7	
7/15/82	26.5	16	11.9	13.4	
7/23/82	28.5	16	12.8	14.3	
7/29/82	28.5	16	12.8	14.3	
8/4/82	28.5	16	12.8	14.3	
8/20/82	28.5	15.5	13.2	14.7	
8/25/82	28.5	15.5	13.2	14.7	
9/7/82	28.5	15.5	13.2	14.7	
9/14/82	28.5	15	13.7	15.2	
9/16/82		14		15	Pail only
9/21/82	23.0	13	12.7	14.2	
9/30/82	28.5	14	14.7	16.2	
10/20/82	28.5	15	13.7	15.2	
10/21/82	26.0	15.5	12.1	13.6	
11/2/82	28.5	12	17.1	18.6	High
11/2/82	28.5	15	13.7	15.2	Adjusted
11/4/82	21.5	13.5	11.5	13.0	
11/4/82	24.5	14.5	12.2	13.7	
11/16/82	26.5	15	12.7	14.2	
11/24/82	27.0	17.5	11.1	12.6	
11/30/82	27.0	17.5	11.1	12.6	
12/7/82	26.5	17	11.2	12.7	
12/8/82	26.5	17	11.2	12.7	
1/17/83		30		7.1	Low (pail only)
1/17/83		17		13.5	Adjusted (pail only)

APPENDIX A. SLOW SAND FILTER FLOW CHECKS - continued

Date	Wt (lbs)	Time (sec)	Minimum Flow Rate gpm	Maximum Flow Rate gpm	Remarks
1/19/83		15		13.5	(Pail only)
2/23/82	26.5	15	12.7	14.2	
2/23/83	26.5	16.5	11.6	13.1	
2/26/83	26.5	19	10.0	11.5	
2/28/83	26.5	11	17.4	18.9	High
2/28/83	26.5	16.5	11.6	13.1	Adjusted
3/7/83	26.5	15	12.7	14.2	
3/15/83	26.5	15	12.7	14.2	
4/12/83	26.5	16	11.9	13.4	
5/16/83	26.5	16	11.9	13.4	
7/6/83	27.5	16.5	12.0	13.5	
7/19/83	26.5	15	12.7	14.2	
8/11/83	27.5	15	13.2	14.7	
10/6/83	25.0	16.5	10.9	12.4	
10/7/83	24.5	15	11.8	13.3	
10/21/83	24.0	13.5	12.8	14.3	
12/8/83	23.5	15	11.3	12.8	
1/3/84	14.5	10	10.4	11.9	
3/12/84	----	10	----	13.6	
4/30/84	19.75	12	11.9	13.4	

APPENDIX B. SLOW SAND FILTER - HEAD LOSS DATA

Date	Influent (cm)	Effluent (cm)	Loss (cm)
4/28/82	21.75	27.25	6.0
5/10/82	cleaned		
5/27/82	-	-	2.0
6/10/82	12.5	13.5	1.0
6/24/82	9.0	11.5	2.5
6/24/82	9.0	11.5	2.5
7/1/82	13.5	15.5	2.0
7/8/82	18.0	20.0	2.0
7/16/82	-	-	3.0
7/23/82	33.25	35.0	1.75
7/29/82	10.5	12.5	2.0
8/4/82	14.0	16.0	2.0
8/20/82	25.0	27.0	2.0
8/20/82	25.75	28.0	2.25
8/25/82	29.5	31.5	2.0
9/7/82	28.0	30.5	2.5
9/14/82	41.5	44.0	2.5
9/16/82	11.2	13.8	2.6
9/21/82	17.25	20.25	3.0
9/30/82	10.7	13.7	3.0
10/20/82	10.0	20.0	10.0
10/21/82	7.5	20.0	12.5
11/2/82	7.5	73.5	66.0
11/2/82	7.5	74.5	67.0
11/4/82	8.0	81.0	73.0
11/4/82	8.0	78.0	70.0
11/16/82	8.0	108.0	100.0
11/24/82	7.5	118.0	110.5
11/30/82	8.0	128.0	120.0
12/7/82	8.5	126.0	117.5

APPENDIX B. SLOW SAND FILTER - HEAD LOSS DATA - continued

Date	Influent (cm)	Effluent (cm)	Loss (cm)
12/8/82	9.5	127.5	118.0
1/1/83	8.0	138.0	130.0
1/17/83	8.0	144.0	136.0
1/17/83	8.0	176.0	168.0
1/19/83	10.5	146.5	136.0
1/20/83	9.0	166.0	157.0
1/24/83	cleaned		
1/25/83	8.0	14.0	6.0
2/23/83	16.5	21.5	5.0
2/28/83	16.5	21.5	5.0
2/28/83	17.5	23.5	6.0
3/7/83	18.3	26.3	8.0
3/15/83	18.3	27.3	9.0
3/22/83	17.5	28.5	11.0
4/12/83	9.5	19.0	9.5
5/16/83	6.5	9.0	2.5
7/5/83	cleaned		
7/19/83	9.5	11.5	2.0
8/9/83	15.25	17.0	1.75
8/11/83	16.5	18.5	2.0
10/5/83	9.0	18.0	9.0
10/7/83	8.75	18.75	10.0
10/12/83	9.5	39.75	30.25
10/20/83	cleaned		
10/21/83	8.5	10.0	1.5
12/30/83	19.0	28.0	9.0
1/16/84	14.5	26.0	11.5
2/28/84	32.0	53.5	21.5
3/1/84	10.5	19.0	8.5
3/1/84	10.5	28.0	17.5
3/12/84	21.5	51.0	29.5
4/9/84	-	-	33.0
4/30/84	14.5	45.0	30.5
5/16/84	-	-	33.5

APPENDIX C. RESIDUAL CHLORINE AND HYPOCHLORINATION OPERATION

	Chlorine Residual Determination				
Date	Residual (mg/L)	Hour Start	Hour End	Elapsed Time (hrs)	Stock Preparation Time (min)
11/19/82	0.7	08:12	09:55	1.71	
11/20/82	0.4	11:15	12:00	0.75	
11/21/82	0.35	11:15	12:00	0.75	20
11/22/82	0.35	08:45	09:00	0.25	
11/23/82	0.45	11:30	12:00	0.50	
11/24/82	0.4	07:30	08:45	1.25	
11/25/82	0.25	12:45	13:30	0.75	
11/26/82	0.3	09:45	10:30	0.75	45
11/27/82	0.3	10:15	10:30	0.25	
11/28/82	0.3	12:15	12:30	0.25	
11/29/82	0.2	09:15	09:30	0.25	
11/30/82	0.3	08:15	08:30	0.25	
12/1/82	0.3	08:15	08:30	0.25	15
12/2/82	0.3	08:30	08:45	0.25	15
12/3/83	0.3	07:15	07:30	0.25	15
12/5/82	0.35	11:45	12:15	0.50	15
12/6/82	0.3	09:15	09:30	0.25	
12/7/82	0.25	08:45	09:00	0.25	
12/8/82	0.25	09:15	09:30	0.25	
12/9/82	0.2	08:15	08:30	0.25	
12/10/82	0.3	08:15	08:30	0.25	25
12/11/82	0.3	11:15	11:30	0.25	15
12/12/82	0.25	11:15	11:30	0.25	
12/14/82	0.25	08:15	08:30	0.25	15
12/15/82	0.25	08:45	09:30	0.75	
12/16/82	0.35	08:45	09:30	0.75	15
12/17/82	0.3	08:45	09:05	0.33	
12/18/82	0.45	11:45	12:00	0.25	15
12/19/82	0.5	11:45	12:15	0.50	15
12/20/82	0.3	08:45	09:00	0.25	

APPENDIX C. RESIDUAL CHLORINE AND HYPOCHLORINATION OPERATION - continued

	Chlorine Residual Determination				
		Hour			Stock Preparation Time (min)
Date	Residual (mg/L)	Start	End	Elapsed Time (hrs)	
12/21/82	0.4	08:45	09:00	0.25	20
12/22/82	0.4	07:15	07:30	0.25	
12/23/82	0.5	08:15	08:30	0.25	
12/24/82	0.4	10:15	10:30	0.25	
12/25/82	0.45	11:45	12:00	0.25	
12/26/82	0.4	11:45	12:00	0.25	20
12/27/82	0.4	10:15	10:30	0.25	
12/28/82	0.4	11:15	11:30	0.25	
12/29/82	0.45	10:15	10:30	0.25	
12/30/82	0.5	09:45	10:00	0.25	
12/31/82	0.5	11:15	11:30	0.25	20
1/1/83	0.4	11:15	11:30	0.25	
1/2/83	0.35	11:15	11:30	0.25	
1/3/83	0.3	09:45	10:00	0.25	
1/4/83	0.35	14:15	14:30	0.25	
1/5/83	0.3	11:15	11:30	0.25	20
1/6/83	0.3	09:45	10:00	0.25	
1/7/83	0.3	11:45	12:00	0.25	
1/8/83	0.35	11:45	12:00	0.25	
1/9/83	0.3	12:15	12:30	0.25	
1/10/83	0.5	11:45	12:00	0.25	20
1/11/83	0.3	09:15	09:30	0.25	
1/12/83	0.3	09:15	09:30	0.25	
1/13/83	0.35	09:15	09:30	0.25	
1/14/83	0.45	08:45	09:00	0.25	
1/15/83	0.45	09:15	09:30	0.25	
1/16/83	0.4	09:15	09:30	0.25	20
2/4/83	1.6	11:45	12:10	0.42	20
2/5/83	2.0	13:45	13:55	0.17	20
2/6/83	1.7	13:45	13:55	0.17	20
2/7/83	2.5	11:45	12:15	0.50	20
2/8/83	2.5	11:45	12:10	0.42	20
2/9/83	2.5	11:45	12:05	0.33	20
5/13/83	0.2	09:35	09:55	0.33	
6/7/83	0.2	10:10	10:30	0.33	

APPENDIX C. RESIDUAL CHLORINE AND HYPOCHLORINATION OPERATION - continued

	Chlorine Residual Determination				
	Residual	Hour		Elapsed	Stock Preparation
Date	(mg/L)	Start	End	Time (hrs)	Time (min)
6/8/83	0.4	09:40	10:00	0.33	
6/9/83	0.5	09:40	10:00	0.33	
6/20/83	0.7	09:40	10:00	0.33	
6/20/83	0.6	11:40	12:00	0.33	
6/21/83	0.7	08:40	09:00	0.33	
6/22/83	1.4	09:10	09:30	0.33	
6/23/83	1.8	08:40	09:00	0.33	
6/24/83	1.1	09:10	09:30	0.33	
6/25/83	1.8	11:40	12:00	0.33	
6/26/83	1.1	11:40	12:00	0.33	5
6/27/83	2.5	10:10	10:30	0.33	5
6/28/83	0.3	09:40	10:00	0.33	5
6/29/83	3.0	09:40	10:00	0.33	5
6/30/83	3.0	09:10	09:30	0.33	5
7/1/83	0.4	11:40	12:00	0.33	5
7/2/83	0.5	09:40	10:00	0.33	5
7/3/83	0.3	15:40	16:00	0.33	5
7/4/83	2.6	16:10	16:30	0.33	5
7/27/83	2.5	11:40	12:00	0.33	5
7/29/83	3.0	11:45	12:15	0.50	5
7/30/83	2.0	11:45	12:15	0.50	5
8/1/83	2.5	08:30	09:00	0.50	5
8/2/83	2.5	11:30	12:00	0.50	5
8/3/83	0.4	11:45	12:15	0.50	5
8/4/84	0	11:50	12:20	0.50	5
8/5/83	0	09:30	10:00	0.50	5
8/7/83	0	11:45	12:15	0.50	5
8/9/83	0.3	08:30	09:00	0.50	5
8/11/83	1.5	07:30	08:00	0.50	5
8/13/83	0.2	12:15	12:45	0.50	5
8/15/83	2.0	08:30	09:00	0.50	5
8/17/83	0.2	10:30	11:00	0.50	5
8/19/83	1.0	07:30	08:00	0.50	5
8/20/83	1.7	13:15	13:45	0.50	5
8/21/83	0.2	14:00	14:30	0.50	5

APPENDIX D. WATER METER CALIBRATION

Date	Meter	Meter Readings		Delta	Flow Rate	Time	Wt.	Flow Rate Time-Wt
		Start	End	(gal)	(gpm)	(sec)	(g)	(gpm)
6/7/84	26989170	185118	185119.6	1.6	0.44	217.5	9004	0.66
6/7/84	26989170	185124	185125	1.0	0.22	269.3	8533	0.50
6/7/84	26989170	184950	184952.45	2.45	0.96	153.2	11150	1.15
6/7/84	26989170	184960	184962	2.0	1.05	114.6	7305.5	1.01
6/7/84	26989170	184971	184972.7	1.7	0.88	116.4	7991	1.09
6/7/84	26989170	185000	185001.7	1.7	1.97	51.75	7502	2.16
6/7/84	26989170	185010	185012	2.0	2.15	55.75	8112	2.31
6/7/84	26989170	185030	185032	2.0	2.26	53.0	8065.5	2.41
6/7/84	26989170	185100	185102	2.0	5.43	22.1	7719	5.54
6/7/84	26989170	185110	185112	2.0	5.58	21.5	7531	5.55
6/7/84	26989170	185115	185117	2.0	5.15	23.3	7590	5.16
6/11/84	26989167	48320	48322	2.0	1.02	117.6	8514	1.15
6/11/84	26989167	48330	48332	2.0	0.96	124.9	8796	1.12
6/11/84	26989167	48337	48339	2.0	0.98	122.7	8707	1.12
6/11/84	26989167	48350	48352	2.0	1.09	57.4	7968	2.20
6/11/84	26989167	48358	48360	2.0	2.09	57.3	8064	2.23
6/11/84	26989167	48367	48369	2.0	2.12	56.6	7962	2.23
6/11/84	26989167	48410	48412	2.0	4.17	28.8	7605	4.19
6/11/84	26989167	48428	48430	2.0	4.14	29.0	7584	4.15
6/11/84	26989167	48450	48452	2.0	4.43	27.1	7550	4.42
6/11/84	26989167	48481	48483	2.0	5.33	22.5	7468	5.26
6/11/84	26989167	48490	48492	2.0	5.38	22.3	7480	5.32
6/11/84	26989167	48496	48498	2.0	5.36	22.4	7502	5.31
8/24/84	26989167	48508	48510	2.0	4.8	25.1	8169	4.9
8/24/84	26989167	48514	18516	2.0	5.0	24.0	7964	5.0

APPENDIX D. WATER METER CALIBRATION - CONTINUED

Date	Meter	Meter Readings Start	 End	Delta (gal)	Flow Rate (gpm)	Time (sec)	Wt (g)	Flow Rate Time-Wt (gpm)
8/24/84	26989167	48517	48519	2.0	4.9	24.5	8135	5.0
8/27/84	26989170	185128	185130	2.0	4.8	25.2	8237	4.9
8/27/84	26989170	185132	185134	2.0	4.8	25.0	8192	4.9
8/27/84	26989170	185136	185138	2.0	4.8	24.9	8125	4.9
8/27/84	26989170	185155	185157	2.0	3.5	31.3	8284	4.0
8/27/84	26989170	185160	185162	2.0	3.5	34.0	7939	3.5
8/27/84	26989170	185164	185166	2.0	3.4	35;6	8103	3.4
8/27/84	26989170	185168	185170	2.0	1.8	65.6	8733	2.0
8/27/84	26989170	185172	185174	2.0	1.8	65.5	8718	2.0
8/27/84	26989170	185176	185178	2.0	1.8	66.3	8754	2.0
8/27/84	26989170	185180	185182	2.0	0.62	194.1	10779	0.84
8/27/84	26989170	185183	185185	2.0	0.57	210.3	10889	0.77
8/27/84	26989170	185186	185187	1.9	0.48	228.7	10889	0.79
8/27/84	26989167	48520	48522	2.0	1.0	116.3	9442	1.2
8/27/84	26989167	48523	48525	2.0	1.0	115.0	9209	1.2
8/27/84	26989167	48526	48528	2.0	1.0	120.3	9688	1.2
8/27/84	26989167	48530	48532	2.0	2.2	55.1	8617	2.3
8/27/84	26989167	48533	48535	2.0	2.2	53.6	8366	2.3
8/27/84	26989167	48536	48538	2.0	2.2	55.7	8658	2.3
8/27/84	26989167	48543	48545	2.0	4.1	29.2	7022	4.1
8/27/84	26989167	48546	48548	2.0	4.0	29.9	8138	4.1
8/27/84	26989167	48550	48552	2.0	4.1	29.3	7985	4.1
8/23/84	26989170	185193	185194	1.0	0.44	132.4	6450	0.69
8/23/84	26989170	185200	185201	1.0	0.44	136.7	6375	0.69
8/23/84	26989170	185202	185203	1.0	0.41	145.3	6623	0.67

APPENDIX D. WATER METER CALIBRATION - continued

Date	Meter	Meter Readings Start	Meter Readings End	Delta (gal)	Flow Rate (gpm)	Time (sec)	Wt (g)	Flow Rate Time-Wt (gpm)
8/23/84	26989167	48555	48556	1.0	0.43	139.6	6372	0.67
8/23/84	26989167	48558	48559	1.0	0.43	139.3	6482	0.69
8/23/84	26989167	48563	48564	1.0	0.44	137.2	6323	0.68

APPENDIX E. WATER METER, FIELD CALIBRATION

Date	Time (Min)	Meter Readings Start	End	Delta (gal)	Flow Rate (gpm)	Time (sec)	Wt (1b)	Flow Rate Time-Wt (gpm)
12/8/82	90:00.0	4250	5680	1430	15.89	13.0	26	14.39
12/8/82	105:00.0	5680	7260	1580	15.05	13.0	27	14.95
12/8/82	100:00.0	7260	8640	1320	13.20	13.0	26	14.39
12/8/82	120:00.0	8640	9590	950	7.92	27.0	28	7.46
12/9/82	40:00.0	11720	11980	260	6.50	26.0	26	7.20
4/12/83	120:00.0	13449	14589	1140	9.50	20.0	28	10.07
4/14/83	30:00.0	19380	19975	595	19.83	11.0	28	18.32
5/17/83	15:00.0	31675	31934	259	17.27	10.0	25.75	18.53
5/19/83	55:00.0	37749	38301.5	552.5	10.05	15.0	22.25	10.67
6/16/83	25:00.0	39239	39437	198	7.92	18.0	25	9.99
6/16/83	30:00.0	29437	39720	283	9.43	18.0	25.5	10.19
8/11/83	39:00.0	47162.3	47492	339.7	10.99	22.0	29.5	9.65
10/3/83	25:00.0	33051	33094	243	9.72	20.0	29.5	10.61
10/6/83	15:00.0	36893.5	37234	340.5	22.70	11.0	29	18.97
10/6/83	52:00.0	37609	38245.8	546.8	10.51	20.0	19	10.43
10/7/83	20:00.0	41025	41257	232	11.6	20.0	28	10.07

Rockwell 5/8 Water Meter

APPENDIX F. RAW WATER CHLORINE RESIDUALS (R) AND CHLORINE DEMAND (D) WITH TIME (mg/L)

	3/82		8/82		12/82		6/83	
Day	R	D	R	D	R	D	R	D
0	15	0	23.8	0	20.0	0	27.2	0
0.1	11	4.0	--	--	15.5	4.5	17.2	10.0
2	6.7	8.3	15	8.8	--	--	--	--
3	--	--	--	--	11.5	8.5	14.1	13.1
5	5.8	9.2	--	--	10.6	9.4	14.2	13.0
6.3	--	--	12.5	11.3	--	--	--	--
7	5.3	9.7	--	--	10.6	9.4	11.5	15.7
9	5.3	9.7	--	--	--	--	--	--
10	--	--	--	--	10.6	9.4	4.4	22.8
11.8	--	--	10.0	13.8	--	--	--	--

APPENDIX G. SLOW SAND FILTER PARTICLE COUNT - NORMAL OPERATION

Date	Raw Water No./1 mL	Effluent No./1 mL	% Reduction
06-18-82	12170	1240	89.8
06-24-82	9400	5390	42.7
07-01-82	8320	1190	85.7
07-08-82	10090	4320	57.2
07-15-82	7080	3350	52.7
07-23-82	10470	3740	64.3
07-29-82	8530	3090	63.8
08-04-82	12200	5910	51.6
08-10-82	19240	840	95.6
08-20-82	9980	2880	71.1
08-25-82	5650	910	83.9
09-07-82	1980	300	84.8
09-14-82	1880	660	64.9
09-21-82	10030	2840	71.1
09-30-82	7670	610	92.0
10-05-82	4940	550	88.9
10-12-82	4750	660	86.1
10-19-82	8960	1570	82.5
10-20-82	4700	310	93.4
10-26-82	47250	220	99.5
11-02-82	15840	1510	90.5
11-09-82	12400	1890	84.4
11-16-82	3030	8250	-172.3
11-23-82	12220	1640	86.6
11-30-82	116190	1210	99.0
12-28-82	6510	2940	54.8
01-11-83	143430	3880	97.3
01-20-83	15250	2710	82.2
02-10-83	4540	2950	35.0
02-16-83	6090	3390	44.3

APPENDIX G. SLOW SAND FILTER PARTICLE COUNT - NORMAL OPERATION - continued

Date	Raw Water No./1 mL	Effluent No./1 mL	% Reduction
02-23-83	3020	1320	56.3
02-27-83	6080	2360	61.2
02-27-83	5410	1370	74.7
03-29-83	8180	630	92.3
03-31-83	6000	2850	52.5
04-03-83	4820	5470	-13.5
04-05-83	4320	1740	59.7
04-12-83	14680	4210	71.3
04-12-83	6960	1700	75.6
04-18-83	3520	1000	71.6
06-01-83	4670	3610	22.7
06-07-83	3570	1580	55.7
06-16-83	4120	2070	49.8
06-30-83	3040	3650	-20.1
08-04-83	3910	5800	-48.3
08-11-83	1450	3770	-16.0
08-17-83	3140	2440	22.3
08-24-83	5720	2660	53.5
09-01-83	5650	4530	19.8
09-08-83	9760	2670	72.6
09-14-83	6260	3840	38.7
09-20-83	10170	850	91.6
09-28-83	12600	4620	63.3
10-05-83	14300	1380	90.3
10-12-83	10120	2760	72.7
10-19-83	7580	3560	53.0
12-21-83	12580	11170	11.2
01-16-84	13880	21810	-57.1
02-14-84	23630	14700	37.8
02-28-84	19870	49160	-147.2
03-12-84	17910	57400	-220.5
04-24-84	4740	2860	39.7

APPENDIX H. SLOW SAND FILTER PARTICLE COUNT - CLEANING RECOVERY

Date	Raw Water No./1 mL	Effluent No./1 mL	% Reduction
		Cleaned 5-10-82	
05-13-82	7890	2920	63.0
05-13-82	4060	1780	31.5
05-17-82	4000	1820	54.5
05-17-82	4560	4260	6.6
05-19-82	18540	660	96.4
05-19-82	4160	1980	52.4
05-24-82	5340	1540	71.2
05-24-82	3980	1600	59.8
05-27-82	4920	1020	79.3
05-27-82	3400	1740	48.4
06-01-82	4250	2300	45.9
06-01-82	6460	600	90.7
06-10-82	9820	1560	84.1
		Cleaned 1-24-83	
01-25-83	979820	6360	99.4
01-25-83	11110	4870	56.2
01-26-83	13050	3490	73.3
01-26-83	6520	2860	56.1
01-27-83	4890	3800	22.3
01-27-83	3330	1660	50.1
01-28-83	2770	2070	25.3
01-31-83	9580	7000	26.9
02-01-83	11600	5250	54.7
02-02-83	2940	2440	17.0
02-03-83	11250	2370	78.9
02-07-83	3470	1940	44.1
02-08-83	5240	3140	40.1

APPENDIX H. SLOW SAND FILTER PARTICLE COUNT - CLEANING RECOVERY - continued

Cleaned 7-5-83

Cleaning Recovery and Sewage Spiking

Date	Raw Water No./1 mL	Effluent No./1 mL	% Reduction
07-06-83	1770	1590	10.2
07-06-83	3180	2280	28.3
07-07-83	5700	2960	48.1
07-07-83	2820	2100	25.5
07-08-83	3680	1380	62.5
07-08-83	2960	1300	56.1
07-10-83	2640	4460	-68.4
07-10-83	2350	3430	-46.0
07-11-83	2680	3580	-33.6
07-11-83	4480	6000	-33.9
07-12-83	2370	4840	-104.2
07-13-83	3330	3560	-6.9
07-14-83	5480	4130	24.6
07-15-83	8030	2560	68.1
07-17-83	1960	3130	-59.7
07-18-83	1450	3570	-146.2
07-19-83	1990	3260	-63.8
07-24-83	2850	3450	-21.1
07-25-83	4830	1970	59.2
07-26-83	3320	2190	34.0
07-27-83	3420	3340	-3.1

APPENDIX I. SLOW SAND FILTER - GIARDIA CYST SAMPLING

Spike Date	Sampling Dates	Water Temp. ° C	Number Cysts Counted	Number Fields	Number Cysts Recovered	Number Cysts Applied	Tagging Dye*
2/28/83	3/1/83	1	321	1	3852	$2.1\text{x}10^6$	F
	3/2/83	1	9	1	108		
	3/3/83	1	6	1	492		
	3/4/83	1	0	1	0		
	3/5/83	1	0	1	0		
	3/6/83	1	0	1	0		
5/16/83	5/16/83	11	2	3	8	$2.1\text{x}10^6$	F
	5/17/83	11	0	3	0		
	5/18/83	11	0	3	0		
	5/19/83	11	0	3	0		
	5/20/83	11	0	3	0		
	5/21/83	11	0	3	0		
	5/22/83	11	0	3	0		
8/8/83	8/8/83	20	4	3	21	$8\text{x}10^6$	F
	8/9/83	20	3	3	16		
	8/10/83	20	0	3	0		
	8/11/83	20	0	3	0		
	8/12/83	20	1	3	5		
12/8/83	12/9/83	1	283	6	756	$2.3\text{x}10^7$	F
	12/10/83	1	354	3	1887		
	12/11/83	1	153	3	815		
	12/12/83	1	54	3	288		
	12/13/83	1	38	6	101		
	12/14/83	1	13	3	69		
	12/15/83	1	7	3	37		
	12/16/83	1	13	3	69		
	12/17/83	1	3	3	16		

APPENDIX I. SLOW SAND FILTER - GIARDIA CYST SAMPLING - continued

Spike Date	Sampling Dates	Water Temp. ° C	Number Cysts Counted	Number Fields	Number Cysts Recovered	Number Cysts Applied	Tagging Dye*
12/8/83	12/18/83	1	0				
	12/19/83	Malfunction--					
	12/20/83	1	4	6	11		
	12/21/83	1	1	3	5		
	12/22/83	1	1	3	5		
	12/23/83	1	1	3	5		
	12/24/83	1	1	3	5		
	12/25/83	1	0	6			
	12/26/83	1	0	3			
	12/27/83	1	0	3			
	12/28/83	1	0	3			
	12/29/83	1	0	3			
	12/30/83	1	0	6			
	12/31/83	1	0	3			
	1/1/84	0.5	0	3			
	1/2/84	0.5	0	3			
	1/3/84	0.5	0	3			
	1/4/84	0.5	1	6	3		
	1/5/84	0.5	0	3			
	1/6/84	0.5	1	3	5		
	1/7/84	0.5	0	3			
	1/8/84	0.5	1	6	3		
	1/9/84	0.5	0				
	1/10/84	0.5	1	3	5		
	1/11/84	0.5	0	3			

APPENDIX I. SLOW SAND FILTER - GIARDIA CYST SAMPLING - continued

Spike Date	Sampling Dates	Water Temp. ° C	Number Cysts Counted	Number Fields	Number Cysts Recovered	Number Cysts Applied	Tagging Dye*
12/8/83	1/12/84	0.5	1	3	5		
	1/13/84	0.5	0	3			
	1/14/84	0.5	0	6			
	1/15/84	0.5	0	3			
	1/16/84	0.5	0	3			
1/16/84	1/17/84	0.5	173	3	922	2.55×10^7	R
	1/18/84	0.5	653	6	1744		
	1/19/84	0.5	72	3	384		
	1/20/84	0.5	19	3	101		
	1/21/84	0.5	6	3	32		
	1/22/84	0.5	5	3	27		
	1/23/84	0.5	0	6			
	1/24/84	0.5	1	3	5		
	1/25/84	0.5	0	3			
48 hr.	1/27/84	0.5	3	3	16		
	1/30/84	0.5	4	6	11		
	1/31/84	1	1	3	5		
	2/1/84	1	1	3	5		
	2/2/84	1	3	3	16		
	2/3/84	1	3	6	16		
	2/4/84	1	1	3	5		
	2/5/84	1	0	3			
	2/6/84	1	1	3	5		
	2/7/84	1	1	3	5		
	2/8/84	1	0	6			

APPENDIX I. SLOW SAND FILTER - *GIARDIA* CYST SAMPLING - continued

Spike Date	Sampling Dates	Water Temp. ° C	Number Cysts Counted	Number Fields	Number Cysts Recovered	Number Cysts Applied	Tagging Dye*
	2/9/84	1	0	3			
	2/10/84	1	0	3			
	2/11/84	1	1	3	5		
	2/12/84	1	0	3			
	2/13/84	1	0	6			
	2/14/84	1	0	3			
2/14/84	2/15/84	1	126	3	672	2.30×10^7	F
	2/16/84	1	395	3	2105		
	2/17/84	1	86	3	458		
	2/18/84	1	55	6	147		
	2/19/84	1	0	3			
	2/20/84	1	4	3	21		
	2/21/84	1	7	3	37		
	2/23/84	0.5	6	3	32		
	2/24/84	0.5	3	6	8		
	2/25/84	0.5	0	3			
	2/26/84	0.5	1	3	5		
	2/27/84	0.5	0	3			
	2/28/84	0.5	1	3	5		
	2/29/84	0.5	1	3	5		
48 hr.	3/2/84	0.5	1	3	5		
48 hr.	3/4/84	0.5	0	3			

APPENDIX I. SLOW SAND FILTER - GIARDIA CYST SAMPLING - continued

Spike Date	Sampling Dates	Water Temp. ° C	Number Cysts Counted	Number Fields	Number Cysts Recovered	Number Cysts Applied	Tagging Dye*
48 hr.	3/6/84	0.5	0	3			
	3/8/84	0.5	0	3			
	3/11/84	0.5	1	6	3		
	3/12/84	0.5	0	3			
3/12/84	3/13/84	0.5	3	3	16	$2.55x10^7$	R
48 hr.	3/15/84	0.5	24	3	128		
	3/16/84	0.5	19	3	101		
	3/17/84	0.5	7	6	19		
	3/18/84	0.5	1	3	5		
48 hr.	3/20/84	0.5	2	3	11		
48 hr.	3/22/84	0.5	19	3	101		
48 hr.	3/25/84	0.5	4	3	21		
	3/26/84	0.5	3	6	8		
	3/28/84	0.5	2	3	11		
	3/30/84	0.5	3	3	16		
	4/1/84	1.0	1	3	5		
	4/3/84	1.0	0	3			
	4/5/84	1.0	10	6	267		
	4/7/84	1.0	2	3	11		
	4/9/84	1.0	1	3	5		

APPENDIX I. SLOW SAND FILTER - GIARDIA CYST SAMPLING - continued

Spike Date	Sampling Dates	Water Temp. ° C	Number Cysts Counted	Number Fields	Number Cysts Recovered	Number Cysts Applied	Tagging Dye*
4/9/84	4/10/84	1.0	0	3		$2.30x10^7$	F
	4/11/84	5	0	3			
	4/12/84	5	0	6			
	4/13/84	5	1	3	5		
	4/14/84	5	0	3			
	4/15/84	5	1	3	5		
	4/16/84	5	0	3			
48 hr.	4/18/84	5	0	6			
48+ hr.	4/21/84	9	1	3	8		
	4/23/84	9	0	3			
	4/24/84	9	0	3			
	4/26/84	9	0	3			
	4/29/84	9	3	6	12		
	5/1/84	10	0	3			
	5/3/84	10	1	3	5		
	5/7/84	10	1 (R)	1	16		
	5/9/84	10	0	3			
	5/11/84	10	0	3			

*F - Fluorscein isothiocynate
R - Tetramethylrhodamine-B-isothiocynate

APPENDIX J. DE FILTRATION - BACTERIA AND PARTICLE REDUCTION

Run No.	Date	Water Temp. ° C	Filtration Rate m/hr	Bacteria Total Coliform/100 mL Inf.	Eff.	Plate Count/mL Inf.	Eff.	Particles No./1 mL Inf.	Eff.
1	12/7/82	5	2.0	1	1	11	6	12400	2830
1	12/7/82	5	2.0		1		6		1750
1	12/7/82	5	2.0	1	1	3	6	3820	3990
1	12/7/82	5	2.0		1		3		2620
1	12/7/82	5	2.0		1		4		1010
2	12/8/82	5	4.6	1	1	29	34	11810	5940
2	12/8/82	5	4.6	14	1	11	1	2830	14120
2	12/8/82	5	4.6		1		10		4040
2	12/8/82	5	4.6		34		8		7530
2	12/8/82	5	4.6	1	1	19	6	5930	4490
3	12/8/82	5	2.6	8	1	18	5	10560	7940
3	12/8/82	5	2.6		1		7		2900
3	12/8/82	5	2.6		4		5		3950
3	12/8/82	5	2.6	1	4	10	5	5620	4140
4	12/9/82	5	2.1	14	1	19	4	18450	3910
4	12/9/82	5	2.1						
4	12/9/82	5	2.1		5		7		1310
4	12/9/82	5	2.1	178	8	350	11	2920	1150
5	4/13/83	2	2.3	60	1	31	8	11410	3960
5	4/13/83	2	2.3		1		8		1770
5	4/13/83	2	2.3	9	1	43	9	6020	1840
5	4/13/83	2	2.3		10		5		750
5	4/13/83	2	2.3		7		2		1600

APPENDIX J. DE FILTRATION - BACTERIA AND PARTICLE REDUCTION - continued

Run No.	Date	Water Temp. ° C	Filtration Rate m/hr	Bacteria Total Coliform/100 mL Inf.	Eff.	Plate Count/mL Inf.	Eff.	Particles No./1 mL Inf.	Eff.
6	4/14/83	3	4.7	20	1	70	2	7240	720
6	4/14/83	3	4.7		1		16		3040
6	4/14/83	3	4.7	45	4	48	3	4430	3230
6	4/14/83	3	4.7		1		17		3280
6	4/14/83	3	4.7	50	1	18	16	6750	2390
7	4/15/83	4	2.4	5	1	7	0	5190	3170
7	4/15/83	4	2.4	5	1	76	7	6310	4460
7	4/15/83	4	4.0		1		1		1620
7	4/15/83	4	4.0		1		1		1170
8	4/15/83	4	3.8	5	1	85	2	4270	1530
8	4/15/83	4	3.8		1		1		3420
8	4/15/83	4	3.8	9	1	12	1	4060	2250
8	4/15/83	4	3.8		1		1		2060
9	4/18/83	4	2.3	9	1	22	150	6740	5130
9	4/18/83	4	2.3	9		16		3520	
9	4/18/83	4	2.3		1		55		2420
9	4/18/83	4	2.3	9	1	27	221	4050	2900
9	4/18/83	4	2.3		1		81		2290
9	4/18/83	4	2.3		1		3		920
10	4/19/83	3	4.6	1	1	12	210	2640	2610
10	4/19/83	3	4.6		1		68		450
10	4/19/83	3	2.7	1	1	13	62	4920	1910
10	4/19/83	3	2.7		1		8		1010
10	4/19/83	3	2.7		1		10		670

APPENDIX J. DE FILTRATION - BACTERIA AND PARTICLE REDUCTION - continued

Run No.	Date	Water Temp. ° C	Filtration Rate m/hr	Bacteria Total Coliform/100 mL Inf.	Eff.	Plate Count/mL Inf.	Eff.	Particles No./1 mL Inf.	Eff.
11	4/20/83	3	4.5	15	1	23	253	1790	870
11	4/20/83	3	4.5		2		153		660
11	4/20/83	3	4.5	9	2	29	107	1840	1900
11	4/20/83	3	4.5		2		4		710
11	4/20/83	3	4.5		18		7		680
12	5/17/83	11	4.5	20	152	37	10	5420	2280
12	5/17/83	11	4.5		110		6		2200
12	5/17/83	11	4.5	350	96	31	9	9500	3900
12	5/17/83	11	4.5		106		9		1260
12	5/17/83	11	4.5	10	70	2050	163	3080	1270
13	5/17/83	11	3.9	10	1	62	0	3730	2030
13	5/17/83	11	3.9		54		5		2860
13	5/17/83	11	3.9	9	68	36	7	7270	2460
13	5/17/83	11	2.4		94		9		1170
13	5/17/83	11	2.4	9	90	53	13	1650	7450
14	5/18/83	10	2.5						
14	5/18/83	10	2.5	30	10	34	2	5690	2310
14	5/18/83	10	2.5		260		29		2170
14	5/18/83	10	2.5	10	260	50	33	3460	2430
14	5/18/83	10	2.5		370		24		2030
14	5/18/83	10	2.5	9	160	54	24	3540	1560
14	5/18/83	10	2.5		590		40		5680
15	5/19/83	10	2.6						
15	5/19/83	10	2.6	220	136	82	79	5540	1830
15	5/19/83	10	2.6		790		76		2850

APPENDIX J. DE FILTRATION - BACTERIA AND PARTICLE REDUCTION - continued

Run No.	Date	Water Temp. ° C	Filtration Rate m/hr	Bacteria Total Coliform/100 mL Inf.	Eff.	Plate Count/mL Inf.	Eff.	Particles No./1 mL Inf.	Eff.
15	5/19/83	10	2.6	140	1150	73	69	3760	32770
15	5/19/83	10	2.6		1440		89		1770
15	5/19/83	10	2.6	120	1260	70	77	4760	1440
16	5/19/83	10	2.4	10	1	91	22	5980	3300
16	5/19/83	10	2.4		4		11		2500
16	5/19/83	10	2.4	90	8	72	25	3670	4290
16	5/19/83	10	2.4	110	8	68	8	4420	3110
17	6/16/83	21	2.1	8700	450	127	7	2430	5930
18	8/8/83	23	3.9	1450	11	240	87		3590
18	8/8/83	23	3.9	80	34	330	67	4000	2920
18	8/8/83	23	3.9	170	69	430	48	4650	1950
18	8/8/83	23	3.9						
19	8/9/83	23	2.7	380	1	890	20	5780	1970
19	8/9/83	23	2.7		8		175		1200
19	8/9/83	23	2.7	200	10	970	196	4370	2180
19	8/9/83	23	2.7		16		151		20670
19	8/9/83	23	2.7	180	12	700	132	8840	1010
19	8/9/83	23	2.7						
20	8/10/83	22	3.8	40	3	340	7	3370	4900
20	8/10/83	22	3.8	120	5	280	12	3040	4210
20	8/10/83	22	3.8	90	5	210	10	5110	2770
21	8/10/83	22	4.2	170	2	200	6	11300	3960
21	8/10/83	22	4.2	80	5	260	50	4110	2790
21	8/10/83	22	2.4		1		33		2700
21	8/10/83	22	2.4	95	1	240	16	4220	2200

APPENDIX J. DE FILTRATION - BACTERIA AND PARTICLE REDUCTION - continued

Run No.	Date	Water Temp. ° C	Filtration Rate m/hr	Bacteria Total Coliform/100 mL Inf.	Eff.	Plate Count/mL Inf.	Eff.	Particles No./1 mL Inf.	Eff.
22	8/10/83	22	2.1	80	1	310	8	3590	1960
22	8/10/83	22	2.1		1		28		1830
22	8/10/83	22	2.1	110	2	305	32	4940	2250
22	8/10/83	22	4.1	50	4	200	44	5780	2510
22	8/10/83	22	4.1						
23	8/11/83	21	3.9	240	1	460	1	2140	2770
23	8/11/83	21	3.9	230	6	410	64	4060	2970
23	8/11/83	21	3.9	2350	13	475	69	3590	2980
24	8/11/83	21	2.3	210	1	450	35	3490	750
24	8/11/83	21	2.3		1		60		2980
24	8/11/83	21	2.3	170	2	530	30	6090	3490
24	8/11/83	21	2.3	55	1	430	35	3380	2260
24	8/11/83	21	2.3						
25	8/12/83	19	2.7	430	3	956	24	3330	1860
25	8/12/83	19	2.7		2		78		1760
25	8/12/83	19	2.7	295	12	940	92	4000	1800
25	8/12/83	19	2.7		13		76		1340
25	8/12/83	19	2.7	415	7	775	80	1760	1380
25	8/12/83	19	2.7						

APPENDIX K: DE FILTRATION - VARIABLE FILTRATION RATE DURING RUN

Run No.	Pressure psi	Changes in Pressure psi	Time (hr)	Rate Pressure Change psi/hr	Filtration Rate m/hr
7	6 - 22	16	3	5.3	4.0
7	4 - 10	6	3	2.0	2.4
10	11 - 26	15	3	5.0	4.6
10	4 - 13	9	3	3.0	2.7
13	10 - 45	35	3	11.7	3.9
13	3 - 22	19	3	6.3	2.4
21	9 - 29	20	1	20.0	4.2
21	0 - 23	23	1	23.0	2.4
22	4 - 19	15	3	5.0	2.1
22	0 - 39	39	2	19.5	4.1

APPENDIX L. TURBIDITY REDUCTION BY DE FILTRATION - CONSTANT BODY FEED

Run No.	Run Date	Run Time hr	Filtration Rate m/hr	Head Change psi	Turbidity		Average % Red.	DE Conc. mg/L
					Influent	Average Effluent		
1	12/7/82	3.1	2.0	29	1.06	0.29	72.6	3.7
2	12/8/82	4.9	4.6	21	1.01	0.48	52.5	3.2
3	12/8/82	3.3	2.6	8	1.00	0.32	68.0	2.8
4	12/9/82	2.8	2.1	18	0.99	0.29	70.7	3.6
5	4/13/83	4.0	2.3	14	1.25	0.21	83.2	3.1
6	4/14/83	1.5	4.7	24	0.86	0.31	64.0	3.2
7	4/15/83	2.0/1.1	2.4/4.0	8/18	1.04/1.06	0.24/0.18	76.9/83.0	3.1/1.8
8	4/15/83	1.4	3.8	9	0.96	0.26	72.9	3.8
9	4/18/83	3.3	2.3	8	0.98	0.20	79.6	3.2
10	4/19/83	0.5/2.0	4.6/2.7	3/5	0.75/0.73	0.28/0.16	62.7/78.1	1.7/2.7
11	4/20/83	1.6	4.5	10	0.89	0.22	75.3	3.3
12	5/17/83	1.4	4.5	14	0.63	0.24	61.9	3.3
13	5/17/83	1.0/1.5	3.9/2.4	8/9	0.67/.71	0.26/0.17	61.2/76.1	1.9/3.1
14	5/18/83	3.75	2.5	29	0.58	0.20	65.5	3.0
15	5/19/83	1.9	2.6	10	0.58	0.22	62.1	2.8
16	5/19/83	2.2	2.4	10	0.63	0.26	58.7	3.1
17	6/16/83	1.4	2.1	56	1.35	0.34	74.8	3.5
18	8/8/83	0.9	3.9	31	1.55	0.55	64.5	3.7
19	8/9/83	2.4	2.7	9	1.66	0.33	80.1	2.8
20	8/10/83	0.9	3.8	10	1.25	0.44	64.8	4.0
21	8/10/83	0.6/0.5	4.2/2.4	11/10	1.43/1.46	0.53/0.33	62.9/77.4	3.7/3.2
22	8/10/83	1.0/0.5	2.1/4.1	5/10	1.54/1.25	0.38/0.40	75.3/77.1	3.3/2.5
23	8/11/83	0.8	3.9	23	1.27	0.47	63.0	3.8
24	8/11/83	1.2	2.3	12	1.38	0.40	71.0	3.3
25	8/12/83	1.5	2.7	12	1.33	0.27	80.0	2.8

APPENDIX L. TURBIDITY REDUCTION BY DE FILTRATION - CONSTANT BODY FEED - continued

Run No.	Run Date	Run Time hr	Filtration Rate m/hr	Head Change psi	Turbidity		Average % Red.	DE Conc. mg/L
					Influent	Average Effluent		
26	10/3/83	1.08	2.55	25	6.58	1.48	77.5	5.9
27	10/4/83	2.0	2.55	23	3.70	0.73	80.3	3.7
28	10/6/83	0.67	4.70	21	3.36	0.88	73.8	3.7
29	10/6/83	2.0	2.45	25	3.00	0.69	77.0	9.0
30	10/6/83	1.3	4.40	20	2.58	0.68	73.6	7.2
31	10/7/83	2.0	2.55	26	3.08	0.85	72.4	19.1
32	10/7/83	0.83	4.45	21	3.04	0.94	69.1	18.2
33	10/11/83	1.58	2.55	26	4.42	1.34	69.7	3.9
34	10/11/83	0.58	4.30	21	4.03	1.47	63.5	36.7
35	10/11/83	1.17	2.40	24	3.70	1.03	72.2	34.8
36	10/12/83	1.00	2.43	26	3.34	1.12	66.5	32.4
37	10/12/83	1.00	2.60	22	3.30	0.78	76.4	9.2
38	10/12/83	2.05	2.55	20	3.07	0.53	82.7	27.6

APPENDIX M. ENGLISH-METRIC CONVERSION

Filtration Rate	2 mgad	=	0.08 m/hr
Length	1 ft	=	0.305 m
	1 yd	=	0.914 m
	1 in.	=	2.54 cm
Area	1 ft^2	=	0.093 m^2
	1 yd^2	=	0.835 m^2
	1 $in.^2$	=	6.45 cm^2
Volume	1 ft^3	=	0.0284 m^3
	1 yd^3	=	0.764 m^3
	1 $in.^3$	=	16.39 cm^3
	1 gal	=	3.785 L
	1 qt	=	0.946 L
	1 cup	=	237 mL
Weight	1 lb	=	0.454 kg
	1 oz	=	28.4 g